Optimising the use of visual and radar observations for the mitigation of wind energy related impacts on Cape Vultures (*Gyps coprotheres*) in the Eastern Cape Province

by

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DECLARATION

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ABSTRACT

Being one of the leading global renewable energy investors over the last few years, South Africa's energy sector is undergoing a rapid transformation. This transformation has been driven by the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) – a competitive bidding process, which has already concluded four bidding windows since 2011. Wind energy has comprised the bulk of the approved projects, thus far. Its accelerated development, however, poses a threat to the country's airborne wildlife. Birds have been amongst the avifauna, most affected by wind energy facilities (WEF), both directly and indirectly. These impacts include collision-induced mortalities, habitat loss, costly avoidance behaviour, and barrier effects, which have been well documented in Europe and the United States. In response to such impending risks, South Africa's environmental sector has drawn up a set of guidelines for baseline studies, pre-construction, and post-construction monitoring of birds. Two of the recommended monitoring techniques are direct or visual observations, and radar observation, which formed the foundation of this study. Due to its morphology, phenology and flight behaviour, the Cape Vulture (*Gyps coprotheres*) is considered as particularly vulnerable to WEFs, and has recently been deemed 'endangered', both locally and globally. Considering the species' somewhat fragile status, using it as the primary subject, only added more significance to the study. The aims were to (1) assess the accuracy of visual observations, and (2) investigate activity patterns amongst Cape Vultures in the Eastern Cape Province, using a marine surveillance radar (EchoTrack Inc.).

The proposed Umtathi Emonyeni WEF near Komga (-32.577°, 27.888°) in the Eastern Cape Province, served as the study site. Here, three radar placement sites were established. Vantage point (VP) and radar observations were conducted simultaneously from October 2014 to June 2015. A total of five replicates were completed in that time, one consisting of 12 days. Four days were spent at each placement site. Visually assessed targets were plotted using a cross-platform Geographical Information System (GIS), which allowed for the recording of coordinates. Parameters captured by the radar included latitudinal and longitudinal coordinates, flight height, reflectivity (size), and the airspeed of each target. Using

customised EchoTrack software, visual and radar tracks were matched with a certain degree of confidence, depending on temporal, spatial and directional margins.

A total of 66.4% of all visual observations were matched with corresponding radar tracks. The mean difference in time and distance, between those tracks, was 108.8s and 262.7m, respectively. Those margins were highly significant between Cape Vultures and other priority species. The dataset also indicated a significant positive relationship between both degree of inaccuracy and the distance of the target from the radar, as well as the degree of inaccuracy and the target's height. Using the visually verified Cape Vulture radar tracks, target airspeed and size were used to distinguish the remaining unverified dataset from other bird tracks. Movement frequency (observations/hour), climbing rate (m/s), and flight height all exhibited similar patterns, with peaks being reached during the middle of the day. Trends in movement frequencies were valid for both visual and radar observations.

Results presented here highlight the inconsistencies that govern visual monitoring. They also demonstrate the broad practical uses of avian radar systems. Implementing a comprehensive pre-construction monitoring regime is of great value to both the developers and bird conservationists. Collecting high-quality data vastly improves the reliability of the mitigation strategies that are put in place, and ensures that impacts are efficiently minimised. This also benefits developers as minimal impacts decrease the probability of costly compensations. While radar's application is limited to bird movements, and still requires augmentation through visual observations, the quality of data produced adds significant value to both research and management decision-making. Obtaining data of such high quality is even more valuable for the conservation of endangered species, like the Cape Vulture.

OPSOMMING

Suid-Afrika is die afgelope paar jaar een van die wêreld se voorste beleggers in hernubare energie en is tans besig om ‘n vinnige transformasie te ondergaan. Hieride transformasie word aangedryf deur die *Renewable Energy Independent Power Producers Procurement Programme* (REIPP) – ‘n kompeterende bie prosses, wat alreeds vier biedding vensters afgesluit het vanaf 2011. Windkrag maak so ver die grootste komponent van die goedgekeurde projekte op. Die versnelde ontwikkeling van windkrag hou egter bedreigings in vir die land se vlieënde wild. Voëls word die ergste van alle vlieënde diere geaffekteer deur wind energie fasiliteite (WEF), beide direk en indirek. Hierdie impakte is goed gedokumenteer in Europa en die Vereenigde State van Amerika en sluit in sterftes veroorsaak deur botsings, habitat verlies, kostelike vermydingsgedrag, en versperrings-effekte. Suid-Afrika se omgewingssektor het gereageer op hierdie bedreigings deur riglyne op te stel vir basislyn studies en pre- en post-konstruksie monitering van voëls. Twee moniteringstegnieke word aanbeveel: direkte of visuele waarnemings, of radar waarnemings. Die twee tegnieke vorm die basis van hierdie projek. As gevolg van die morfologie, fenologie en vlieg gedrag word die Kransaasvoël (*Gyps coprotheres*) beskou as besonder kwesbaar vir WEFe, en is onlangs plaaslik en internasionaal gelys as ‘bedreig’. Die gebruik van die bedreigde Kransaasvoël as hoof onderwerp in hierdie navorsing dra dus by tot die belangrikheid en beduidenheid van hierdie projek. Die doelstellings van hierdie studie was om (1) die akuraatheid van visuele waarneemings te evalueer, en (2) aktiwiteitspatrone van Kransaasvoëls te ondersoek in die Oos-Kaap met gebruik van ‘n mariene waarneming radar (EchoTrack Inc.).

Die studie area was die voorgestelde Umtathi Emonyeni WEF naby Komga (-32.577^{o}, 27.888^{o}) in die Oos-Kaap. Die radar is op drie plasingspunte opgestel. Visuele uitkykpunt (VP) en radar observasies is gelyktydig uitgevoer vanaf Oktober 2014 tot Junie 2015. ‘n Totaal van vyf replikas is tydens die periode voltooi, en elke replika het 12 dae geduur. Vier dae is spandeer by elke radar plasingspunt. Visuele geassesseerde teikens is geplot met behulp van ‘n kruis-platform Georafiese Informasie Sisteem (GIS), wat toegelaat het vir die opname van koordinate. Die radar het lengte- en breedtegrade, vlug hoogte, weerkaatsing (grootte) en die lugspoed van elke teiken opgeneem. EchoTrack sagteware is gebruik omvisuele en

radar spore te vergelyk met ‘n redelike mate van vertroue, afhangende van temporale, ruimtelike en rigting marges. ‘n Totaal van 66.4% van alle visuele waarneemings het gepas by ooreenstemmende radar spore. Die algemene verskil in tyd en afstand tussen daardie spore was 108.8s en 262.7m onderskeidelik. Die marges was hoogs beduidend tussen Kransaasvoëls en ander prioriteit spesies. Die data stel het ook aangedui dat ‘n beduidende positiewe verhouding bestaan tussen die graad van onakkuraatheid en die afstand van die teiken vanaf die radar, asook die graad van onakuraatheid en die hoogte van die teiken. Deur die gebruik van die geverifieerde Kransaasvoëls radar spore kon teiken lugspoed en grootte gebruik word om die ongeverifieerde datastel van ander voëls se radar spore te identifiseer. Bewegings-frekwensie (waarnemings/uur), klim koers (m/s), en vlug hoogte het soortgelyke patrone gevolg, en hoogtepunte is tydens die middle van die dag bereik. Tendense in bewegings-frekwensies was geldig vir beide visuele en radar waarnemings.

Die resultate wat hier aangebied word beklemtoon die teenstrydighede van visuele waarnemings. Verder toon die resultate dat pre-konstruksie monitering van kardinale belang is vir beide die ontwikkelaars en die bewaringsekoloë. Die versameling van hoë gehalte data verbeter die vertroubaarheid van die versagting strategië wat in plek gestel word, en verseker dat impakte op voëls doeltreffend verminder word. Dit bevoordeel ook ontwikkelaars, aangesien ‘n afname in impakte die waarskynlikheid van kostelike vergoeding verminder. Terwyl die radar se toewending beperk is tot slegs die voëls se bewegings, en gelyktydige visuele waarnemings toegevoeg moet word, dra die hoë gehalte van die data wat verkry word by tot navorsing en besluitneming. Verkryging van sulke hoë gehalte data is selfs meer belangrik vir die bewaring van bedreigde spesies, soos die Kransaasvoël.

LIST OF ACRONYMS AND ABBREVIATIONS

ASR – airport surveillance radar

ARSR – air route surveillance radar

BASH – bird aircraft strike hazard

BAWEF – Birds and Wind Energy Forum

BAWESG – Birds and Wind Energy Specialists Group

BLSA – BirdLife South Africa

CO_2 – carbon dioxide

DME – Department of Minerals and Energy

EIA – environmental impact assessment

EMRA – European Network for Radar Surveillance of Animal Movement

EWT – Endangered Wildlife Trust

FOV – field of view

GIS – Geographical Information System

IRP – Integrated Resource Plan

IUCN – International Union for Conservation of Nature

NRM – natural resource management

NERSA – National Energy Regulatory of South Africa

OPERA – Operational Programme for the Exchange of Weather Radar Information

PPA – Power-Purchase Agreement

REFIT – Renewable Energy Feed-In Tariff

REIPPP – Renewable Energy Independent Producer Procurement Programme

RSA – rotor swept area

TDOA – time difference of arrival

WEF – wind energy facility

WSR – weather surveillance radar

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CHAPTER ONE

1. General Introduction

1.1. Wind Energy in South Africa

Since the installation of the first electricity-generating wind machine in Cleveland, Ohio, back in 1888, the concept of wind energy has grown into a global phenomenon (Pasqualetti et al. 2004; Kaldellis & Zafirakis 2011). Despite its early inception, the large-scale development of wind power only occurred over the last three decades (Sorensen 1995; Kaldellis & Zafirakis 2011). This rapid expansion was primarily driven by soaring electricity prices and an overwhelming dependence on fossil fuels (de Carmoy 1978; Sorensen 1995). The somewhat sudden development of wind-energy-harnessing technology opened up a largely untapped market in the 1980s (Gipe 1991). While still cost-driven, the recent environmental movement associated with climate change has further propelled the development of renewable energy, due to its carbon-free operation.

South Africa's renewable, and more specifically, wind energy sector has been the subject of rapid development over the last few years (GWEC 2014; Walwyn & Brent 2015). Ranking amongst the top ten global investors in renewable energy in 2012 (USD 5.7 billion), 2013 (USD 4.9 billion) and 2014 (USD 5.5 billion) [REN21 2013, 2014, 2015], has exemplified the country's hastened divergence from a carbon-intensive economy. As the world's seventh largest producer of coal (IEA 2014) and a predominantly coal-dependent energy sector, this is a welcomed development for South Africa. The transition to renewable energy was kick-started by the Department of Minerals and Energy's (DME) publication of the White Paper on Renewable Energy in 2003 (DME 2003). As a supplementation to the White Paper on Energy Policy of 1998, this document outlines the South African government's strategy and objectives in the introduction and implementation of renewable energy (DME 2003). An annual contribution of 10 Terawatt hours (TWh) towards the final energy consumption by the year 2013 was set as a target (DME 2003). In 2009, in an attempt to achieve the said target, the National Energy Regulatory of South Africa (NERSA) ratified the Renewable Energy Feed-In Tariff (REFIT) [Pegels 2010; Eberhard et al. 2014; Msimanga & Sebitosi 2014].

Shortly after its launch, however, REFIT was decommissioned and replaced by what is now known as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) [DoE 2012]. This tender process restricts bids to on-grid projects with capacities exceeding one Megawatt (MW) [DoE 2012]. On 16 April 2015 the preferred bidders from the fourth bid window were announced in a media statement by South Africa's Minister of Energy (DoE 2015a). An additional 13 bidders were announced on 7 June 2015, ultimately adding another 1084MW to the total installed capacity (DoE 2015b). This has taken the total number of projects approved by the DoE to 92, across all windows, and amounts to a total capacity of 6327MW, upon completion (DoE 2015b).

South Africa's wind power industry was essentially launched by the construction of the Darling Wind Farm in 2008 (Msimanga & Sebitosi 2014). The site, located approximately 80 kilometres north of Cape Town, was initially prospected by the Oelsner Group, Germany's AN Windenergy GmbH and Denmark's Bonus Energy, in 1997 (Duguay 2011; Msimanga & Sebitosi 2014). The four-turbine facility was erected by the Darling Independent Power Producer (Pty) Ltd, while Danida, a Danish government funding agency, the Development Bank of Southern Africa (DBSA) and the Central Energy Fund (CEF) provided financial support (Msimanga & Sebitosi 2014). The facility's 5.2MW installed capacity is set to be augmented by a further six 1.3MW-turbines, which will mark Phase 2 of the project (Musango et al. 2011). In 2000 already it was declared a national demonstration project, as it represented the first grid-connected wind energy facility (WEF) in the country (Otto 2000). The Darling National Demonstration Wind Farm, along with Electrawinds/Fluopro, are currently the only two wind power generators holding a power-purchase agreement (PPA) outside of the REIPPPP (DTI 2015).

Even though it took South Africa a decade to install its first 10MW of wind-generated electricity, a staggering 560MW were added to the total installed capacity in 2014 alone (GWEC 2014). This equated to an investment of approximately USD 1.6 billion (REN21 2015). The Integrated Resource Plan (IRP) promulgated by the DoE in 2011 initially projected a capacity of 9200MW for wind power by 2030 (DoE 2011; DoE 2013). As of 30 June 2015, South Africa has procured 3356MW in onshore wind energy through the REIPPPP, of which 790MW are already operational (DoE 2015b). With Round 5 of the REIPPPP set to commence in 2016 and a wealth of wind resources (Szewczuk & Prinsloo 2010), South Africa's wind energy sector is expected to continue growing over the next decade or so. Extant infrastructure is already worth an estimated ZAR 44 billion (GWEC 2014).

While the transition to renewable energy looks to alleviate environmental pressure, with South Africa being the 19th largest emitter of carbon dioxide (CO_2) in 2014 (Olivier et al. 2014), it also offers economic incentives. The highly competitive market created by the REIPPP has seen the average bid prices for wind-generated electricity drop from 1.14ZAR/kWh in Round 1 to 0.66ZAR/kWh in Round 3 (Eberhard et al. 2014).

1.2. Birds and Wind Energy

The hastened departure from fossil-fuel-based energy looks to provide some much needed environmental relief, in the face of climate change. While renewable energy is fulfilling its purpose by reducing the rate of greenhouse gas (GHG) emissions and our overreliance on non-renewable resources, its development does come at a price. Wind energy, in particular, has been scrutinised for its impact on airborne wildlife, and more specifically birds (Kuvlesky et al. 2007; Rydell et al. 2012; Gove et al. 2013).

While the obvious collision risk is commonly recognised as the principal threat, a variety of direct and indirect impacts are dictated by several factors (Barrios & Rodriguez 2004; Marques et al. 2014; Dai et al. 2015). These impacts are generally categorised into four groups: (1) collision risk, (2) habitat loss, (3) displacement, and (4) barrier effects (Drewitt & Langston 2006; Saidur et al. 2011).

Wind turbines seem to provoke fewer bird collisions than other anthropogenic infrastructure – e.g. buildings and power lines (Calvert et al. 2013; Hovick et al. 2014; Wang et al. 2015). That, however, should not detract from the risks associated with these structures. Several well-documented cases have already demonstrated the impact of the poor placement of WEFs. These, most prominently, include studies conducted in the Altamont Pass Wind Resource Area in California, Smøla in Norway and in Tarifa in southern Spain, where considerably high mortality rates amongst Golden Eagle (*Aquila chrysaetos*), White-tailed Eagle (*Haliaatus albicilla*) and Griffon Vulture (*Gyps fulvus*), respectively, have been recorded (Smallwood & Thelander 2008; de Lucas, Ferrer, Bechard & Muñoz 2012) and have contributed towards reduced breeding success and survival rates (Nygård et al. 2010; Dahl, Bevanger, Nygård, Røskaft & Stokke 2012). While these have been isolated occurrences, the threat remains ubiquitous. Recent findings from Loss et al. (2013), and Smallwood (2013) have also suggested that annual bird collisions in the United States had previously been significantly underestimated (Manville 2005; Sovacool 2012). These estimates range from 10 000 to 573 000 bird mortalities per year (Manville 2005; Smallwood 2013).

Collision risks depend on a number of factors (Barrios & Rodriguez 2004; de Lucas et al. 2008; Dai et al. 2015), which Marques et al. (2014) categorised into species-specific, site-specific and wind farm-specific. Species-related factors range from bird behaviour and abundance to the morphology and phenology of the species, as well as sensory perception (Marques et al. 2014). Factors specific to the site include weather, landscape features, and food availability, while wind farm-specific factors refer to the layout of a WEF and the design of the turbines (Marques et al. 2014). Several researchers have advocated an interactive relationship between these factors (Barrios & Rodriguez 2004; Hoover & Morrison 2005). Morinha et al. (2014), for example, recently assessed sex- and age-biased mortalities amongst Skylarks (*Alauda arvensis*) at nine wind farms in northern Portugal. Their results revealed that 90.9% of Skylark carcasses were adult males. Such a demographic bias could have severe implications for small isolated populations (Steifetten & Dale 2006; Schaub 2012; Bellebaum et al. 2013). Furthermore, it highlights the need to instil a multidisciplinary culture within this field of study, to gain more insight into the dynamics of collision-induced fatalities (Loew et al. 2013; Wang & Wang 2015). Long-lived species, with low reproductive rates and slow maturity, are particularly susceptible to wind turbines (Whitfield et al. 2004; Dahl et al. 2012). This includes raptors, who have been at the centre of most bird collision risk assessments (Hoover & Morrison 2005; Telleria 2009; Carrete et al. 2012; Ferrer et al. 2012; Bellebaum et al. 2013).

Given that collision-induced mortalities and their impacts on bird populations are relatively easy to quantify, they have dominated the research domain (Rydell et al. 2012). Some authors have, however, mooted that the repercussions of habitat loss, displacement and barrier effects pose an even greater threat to breeding populations of certain bird species (Kuvlesky et al. 2007; Zeiler & Grünschachner-Berger 2009; Pearce-Higgins et al. 2012; Hovick et al. 2014). Much like the direct impacts associated with collisions, the adverse effects associated with avoidance behaviour and habitat loss vary between site, wind farm and species (Madders & Whitfield 2006; de Lucas et al. 2008; Campedelli et al. 2013). Reduced site fidelity and its repercussions on populations' breeding success is one such effect. A multi-site and multi-species study conducted by Pearce-Higgins et al. (2012) suggests that displacement during construction may have the most significant impact on breeding populations. Based on this and a previous study, snipe and curlew populations, for example, exhibited a marked decline in mean density during and after wind farm construction in the United Kingdom (Pearce-Higgins et al. 2009; Pearce-Higgins et al. 2012). These results are in agreement with those of Campedelli et al. (2013), who observed a substantial decrease in habitat use amongst raptors at a wind farm in northern Italy. The authors do, however, also present evidence of positive population responses amongst certain species, to the construction and operation of a WEF (Pearce-Higgins et al. 2012). Similarly, Garcia et al. (2015) observed decreased population trends amongst certain passerine species during wind farm construction, but an overall increase once the facility was operational. Other studies have found little to no impacts (Hatchett et al. 2013; Hale et al. 2014; Hernández-Pliego et al. 2015). Both negative and positive responses are often associated with a change in vegetation structure (Drewitt & Langston 2006). These changes influence the food available to certain species and can, in turn, skew predator-prey interactions (Rabin et al. 2006; Gove et al. 2013). While increased food availability within a wind farm may benefit some birds, it also magnifies the collision risk (Gove et al. 2013).

As more evidence of wind-energy-related impacts, and their complex and cumulative nature is emerging, the need and potential for further research and mitigation is becoming increasingly apparent (Wang et al. 2015). This is especially true for rapidly expanding wind energy industries, such as South Africa's. With legislation and policies in place to ensure the effective mitigation of such impacts (National Environmental Management Amendment Act No. 62 of 2008), it is essential to further our understanding of them. In 2010 the Birds and Wind Energy Specialist Group (BAWESG), and the Birds and Wind Energy Forum (BAWEF) were convened by BirdLife South Africa (BLSA) and the Endangered Wildlife Trust (EWT) in an attempt to address these issues. These attempts have included the compilation of the recently revised Birds and Wind Energy Best Practice Guidelines (Jenkins et al. 2015) and the Avian Wind Farm Sensitivity Map of South Africa (Retief et al. 2011). While these are necessary precautionary steps, South Africa's hurried transition to renewable energy demands equally urgent research outputs, in order to protect particularly vulnerable species such as the Bearded Vulture (*Gypaetus barbatus*) and the Cape Vulture (*Gyps coprotheres*) [Retief et al. 2011; Rushworth & Krüger 2014].

1.3. Radar Ornithology

Since Lack and Varley (1945) came to the conclusion that mysterious radar reflections were, in fact, caused by birds, the use of radar technology has been applied with great effect, to detect, monitor and quantify flight patterns of birds (Eastwood 1967; Bruderer 1997; Gauthreaux & Belser 1998). This now well-established discipline is commonly referred to as radar ornithology and has become a valuable conservation tool (Gauthreaux & Belser 2003). While this discovery has allowed us to study bird movements with unrivalled accuracy and in poor visibility, the practicality of its application holds the greatest appeal.

Gauthreaux (1985) first applied radar technology in a conservation context, by using a mobile marine surveillance radar unit to assess collision risks at power lines in California. Since then radar has been used to monitor bird aircraft strike hazards (BASH) and collision risks near anthropogenic structures, in particular on- and off-shore WEFs (Nohara et al. 2011; Ronconi et al. 2014). With an expanding application spectrum, radar ornithology has also advanced technologically. The commercialisation of avian radar systems in the late 1990s, in particular, accelerated their development (Nohara et al. 2011).

Technologies vary, however, based on research needs or management strategies. Small, low-powered, Doppler-traffic radars have allowed us to measure the ground speed of short-range avian targets (Evans & Drickamer 1994, Brigham et al. 1998). Meanwhile, military tracking radars have been used to extract information on the altitudinal and density distribution of targets (individuals or flocks), by tracking targets within the radar's scan volume and plotting the trajectory in three dimensional space (Williams 1984; Bruderer et al. 1995). Moreover, high-powered, long-range surveillance radars are able to quantify bird movements at distances ranging between 80 km and 240 km (Gudmundsson 1993; Gauthreaux & Belser 1998; Diehl et al. 2003; Desholm et al. 2014). These include weather surveillance radars (WSR), airport surveillance radars (ASR), and air route surveillance radars (ARSR)

[Gauthreaux & Belser 2003]. The increase in range of detection usually comes at a cost in other attributes, such as minimum altitude at which birds can be detected, and poor range resolution (Millikin 2005).

The National Weather Service (NWS) of the United States upgraded its WSR network in the early 1990s, installing 151 Doppler WSR units (WSR-88D). This vastly extensive network has allowed researchers to monitor migratory behaviours, distribution and abundance on a considerably larger scale (Russell et al. 1998; Larkin et al. 2002; Diehl et al. 2003; Gauthreaux et al. 2003; Bonter et al. 2009). After Larkin (1991) first assessed the bird detection capacity of the WSR-88D, a number of studies have further contributed towards quantifying avian targets and their movements with these radars (Black & Donaldson 1999; Gauthreaux & Belser 1999; Randall et al. 2011; Buler et al. 2012). The Operational Programme for the Exchange of Weather Radar Information (OPERA) network in Europe has been utilised to a similar, though lesser effect (van Gasteren et al. 2008; Dokter et al 2011). In 2014 the European Network for Radar Surveillance of Animal Movement (ERAM) was established, in an attempt to gain more insight into large-scale avifaunal activity across the European continent (Shamoun-Baranes et al. 2014). The information exchanged within this vast research network is extracted from the OPERA radars (Shamoun-Baranes et al. 2014).

Due to their availability, versatility and affordability, marine surveillance radars (S- and X-band) are commonly employed for environmental impact assessments (EIA), natural resource management (NRM), and BASH (Deng & Frederick 2001; Nohara et al. 2007). Their deployment as mobile units has proven to be particularly useful in assessing any wind-energy-related impacts on birds (Mabee et al. 2006; Villegas-Patraca et al. 2014).

Nohara et al. (2007) have grouped past and present technological advances in radar ornithology into three categories. These have been defined as manual target extraction (before 2000), automated target extraction (after 2000), and multi-sensor integration and fusion (after 2005) (Nohara et al. 2007). The integration of multiple sensors stems from radars' most notable limitation – the relative inability to not only distinguish between bird species, but other flying biological targets (i.e. bats and insects) or clutter (Eastwood 1967). Discriminating birds from other targets has become a reasonably simple task, by developing target-specific algorithms (Bruderer & Boldt 2001; Bachmann & Zrnic 2007; Schmaljohann et al. 2008). The same applies to species discrimination, which is, however, prone to less discrete overlaps and lower confidence levels of accurate target identification (Lilliendahl et al. 2003). Such an algorithm, for example, extracts target tracks based on variables, such as target size (intensity of radar signal) and groundspeed (Plonczkier & Simms 2012).

Several efforts have, however, been made to address such shortcomings. One such solution has included attempts to determine signature wing-beat frequencies of certain birds (Zaugg et al. 2008). While not entirely reliable, this technique can be used to identify groups of birds with similar flight behaviours (Bruderer et al. 2010), which is a valuable risk assessment tool. More commonly, however, radar observations have been supplemented by direct visual or other digital monitoring techniques (e.g. satellite telemetry, thermal imaging, radio telemetry, microphones, etc.) [Millikin 2001; Bigger et al. 2006; Gauthreaux & Livingstone 2006; Beason et al. 2010].

The use of radar technology in South Africa has been limited to a handful of EIAs at proposed WEFs and the recently constructed King Shaka Airport in Durban (pers. comm.). Considering the country's rapidly developing renewable energy sector (see 1.1) and its impacts on birds (see 1.2), South Africa is now faced with compiling an effective monitoring protocol that ensures the survival of priority species (Retief et al. 2011). Even though Jenkins et al. (2015) recommend the use of radar systems, their employment costs have thus far constricted the technology's local marketability. Despite its limitations, the unbiased and visibility-independent observations that radar provides, has proved to be invaluable for both research and assessments. While ground-based observations offer another dimension, their inaccuracies make them an unreliable primary monitoring method (Harmata et al. 1999; Cooper & Blaha 2002; Bigger et al. 2006). Out of the 846 bird species in the country, 105 were considered priority species and deemed vulnerable to wind energy developments (Retief et al. 2011). This project's focal species, the Cape Vulture, was assigned the second highest priority score (Retief et al. 2011).

1.4. The Cape Vulture *Gyps coprotheres*

The Cape Vulture or Cape Griffon is an Old World vulture species endemic to the southern African subcontinent (Mundy et al. 1992). Old World vultures comprise two subfamilies within the family Accipitridae (eagles, hawks, kites, buzzards, harriers and vultures), namely Aegypiinae and Gypaetinae (Mundy et al. 1992; Lerner & Mindell 2005). The former constitutes the core of the Old World vultures' phylogeny, and includes the Cape Vulture (Lerner & Mindell 2005).

The body length of these birds generally ranges from 100cm to 118cm, while their wing span can reach 2.3m (Sinclair et al. 2011). Adults are primarily cream-coloured with dark tail and flight feathers. The underwing is comprised of silver-white secondary feathers and black alulae, while their exposed head and neck skin exhibits a greyish blue tone. The beak and eyes are black and yellow in colour, respectively. Juveniles are slightly darker, with more brownish eyes and a red neck.

Vocalisation amongst Cape Vultures is rare and, according to literature, only audible at breeding colonies or roosts (Sinclair et al. 2011). These vocalisations are composed of a variety of hissing, grunting and cackling.

These birds generally lay a single egg (Piper et al. 1981; Mundy 1982) over a period of two months, beginning in April/May (Boshoff & Currie 1981; Robertson 1986; Borello & Borello 2002). The egg hatches about eight weeks after being laid, followed by an estimated 140-day nestling stage (Piper et al. 1981; Robertson 1986). After fledging in November/December, juveniles eventually leave the colony once the next breeding season starts (Piper et al. 1981; Mundy 1982). As most of the juveniles disperse across the sub-continent, the spatially heterogeneous populations consist of nestlings, dependent or attached juveniles, unattached or nomadic immature individuals, and seemingly settled adults (Piper et al. 1981).

Like most vulture species in the region, *G. coprotheres* is a scavenger of ungulate carrion (Mundy 1982). Due to modern land use, the Cape Vulture is largely dependent on livestock as its primary food source (Robertson & Boshoff 1986; Komen & Brown 1993).

Once prevalent across the region, the range of the Cape Vulture has been dramatically constricted over the last few decades. The distribution of breeding colonies is largely concentrated within two regions (Mundy et al. 1992). The first of which includes the former northern Transvaal (Benson et al. 1990; Whittington-Jones et al. 2011), and the other stretches from western KwaZulu-Natal (Brown & Piper 1988), across the highlands of Lesotho and the former Transkei (Mundy et al. 1992; Boshoff et al. 2009b). While estimates suggest that the vast majority of the global population is confined to South Africa and Lesotho (Piper 1994, Botha et al. 2012), remnant colonies still exist in northern Namibia (Brown 1985; Bamford et al. 2007), Zimbabwe and eastern Botswana (Borello & Borello 1987; Borello & Borello 2002; Botha et al. 2012).

A recent assessment by Boshoff et al. (2009b) suggests that the majority of the breeding population within the Eastern Cape Province (Eastern Cape hereafter) is based in the province's eastern section and was estimated to be at least 630 breeding pairs strong. Moreover, approximately 1702 individuals was a conservative estimate of the entire Cape Vulture population within the Eastern Cape, with 2000 individuals deemed a more accurate estimate (Boshoff et al. 2009b). The authors also suggest that all regular roosts and active breeding colonies are located within or in close proximity (<50km) to the borders of the former Ciskei and Transkei (Boshoff et al. 2009b). The somewhat lacking or relatively poor infrastructure of these territories has restricted accessibility and has thus limited research efforts. Hence, some colonies may still be undiscovered. Due to the birds' cliff-nesting habit, monitoring efforts are further hindered. This also adds to the Cape Vulture's vast ranging and partial migratory behaviour (Boshoff et al. 2009a). Despite its relative discontinuity, unpublished data from 2013 estimate the global breeding population of Cape Vultures to be under 3000 pairs (Wolter et al. 2014). Assuming population growth has remained somewhat constant over the last decade or so, this would imply that almost a quarter of all Cape Vulture breeding pairs reside in the Eastern Cape.

The Cape Vulture has been the subject of extensive research efforts and conservation action since the 1950s (Paterson 1952; Jarvis et al. 1974; Mundy et al. 1980; O'Connor 1980; Mundy et al. 1992). Its population has, however, been experiencing a downward trend since the beginning of the 20th century (Ogada et al. 2012). In the eastern parts of South Africa, the local population has experienced a 60-70% decline since 1990 (McKean & Botha 2007). In a proposed subcontinental conservation plan for the species, Boshoff & Anderson (2006) compiled a list of 16 mortality factors that affect the Cape Vulture. These included habitat loss, electrocutions, collisions with wires and cables, carrion contamination, and unsustainable harvest for traditional medicine (Boshoff & Anderson 2006). Most of these threats have been prevalent for over a century now. Their impact was already illustrated by the Cape Vulture's inclusion in the first publication of the South African Red Data Book for Birds in 1976, where its status was described as 'vulnerable and threatened' (Siegfried et al. 1976). The latest edition of the Eskom Red Data Book of

Birds of South Africa, Lesotho and Swaziland (Taylor et al. 2015) considers the Cape Vulture to be locally endangered. Following a recently conducted population assessment by BirdLife International, the species' global population has now also been listed as 'endangered' on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (BirdLife International 2015). A recent review of past and present population trends amongst African vultures (Ogada et al. 2015) suggests that the global Cape Vulture population is declining at a rate that warrants an uplisting to 'critically endangered' (IUCN 2012), for which evidence is, however, insufficient (BirdLife International 2015).

Due to a lack thereof in South Africa, wind turbines were not yet considered a threat to these birds in the conservation plan of Boshoff and Anderson (2006). With South Africa's wind energy industry now in full swing, the task of ensuring the Cape Vulture's survival is becoming increasingly challenging.

1.5. Objectives

The aim of this study was:

1. To test the accuracy of vantage point (VP) observations, using a marine surveillance radar
   - 1.1. How great is the temporal and spatial delay between VP and radar observations?
   - 1.2. How accurate is the vertical estimation of a target?

2. To investigate the use of radar in monitoring activity patterns of Cape Vultures
   - 2.1. Is it possible to develop a radar algorithm for the extraction of Cape Vulture tracks?
   - 2.2. How did Cape Vulture movement frequency, climbing rate and flight height vary daily?

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CHAPTER 2

2. Using a Marine Surveillance Radar to Assess the Accuracy of Visual Monitoring of Cape Vulture (*Gyps coprotheres*) Movements at a Proposed Wind Farm in the Eastern Cape Province, South Africa

Abstract: *South Africa's rapidly expanding wind energy industry is providing much needed alleviation from an ongoing energy crisis. Its development, however, does bear environmental repercussions, which most notably include its impact on birds. Collision risks, habitat loss and barrier effects are amongst the threats, which require effective mitigation efforts. Avian radar systems have vastly enhanced these efforts, and one such system was applied in this study to assess the accuracy of the generally more employed visual monitoring efforts, with a focus on Cape Vultures (Gyps coprotheres) in the Eastern Cape Province. Paired radar and visual observations returned significant margins in time and distance between Cape Vulture tracks and those of other priority species on-site. Simultaneous monitoring efforts also revealed strong relationships between altitudinal misjudgement and height of the target, as well as distance of the target from the radar. Cape Vulture flight and foraging behaviour makes it a challenging target for direct observers. The results of this study suggest that the employment of radar technology for avian movement assessments at wind farms should become a regularity, and can be effectively supplemented with visual observations.*

Keywords: radar, visual observations, Cape Vulture, wind energy, Eastern Cape Province

2.1. Introduction

As one of the top ten global investors in renewable energy over the last three years (REN21 2013, 2014, 2015), South Africa has signalled its intent to fast-track its transition to a greener economy. A predominantly coal-dependent economy (EIA 2015), dwindling coal reserves (Hartnady 2010) and an ongoing energy crisis only further ratify this development. The publication of the White Paper on Renewable Energy in 2003 laid the foundation for the introduction and implementation of renewable energy in South Africa (DME 2003). As an incentive to accelerate development, and meet the targets set in the White Paper, the Renewable Energy Feed-In Tariff (REFIT) was sanctioned in 2009 (Pegels 2010; Eberhard et al. 2014; Msimanga & Sebitosi 2014). This was, however, short-lived, as the REFIT was soon replaced by the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) [DoE 2012]. Having concluded the fourth bidding window in June 2015, the REIPPP has already seen a total of 92 projects approved, which amounts to a capacity of 6327MW (DoE 2015).

After being declared a national demonstration project in 2000, the Darling Wind Farm, represents South Africa's first grid-connected wind energy facility (WEF) (Otto 2000; Msimanga & Sebitosi 2014). After an initial capacity of 5.2MW was installed, plans were drawn up to add a further 7.8MW (Musango et al. 2011). This facility along with Electrawinds/Fluopro, are currently the only two wind power generators holding a power-purchase agreement (PPA) outside of the REIPPPP (DTI 2015).

While South Africa spent a decade installing its first 10MW of wind-generated electricity, 2014 alone saw 560MW added to the total installed capacity (GWEC 2014). A reviewed edition of the Integrated Resource Plan (IRP), which was promulgated in 2011 (DoE 2011), has set a 9200MW target for onshore wind energy for 2030 (DoE 2013). To date, onshore wind energy has comprised more than half of the total renewable energy capacity procured across all bidding windows (DoE 2015). With the success of the REIPPPP, and South Africa's wealth of wind resources (Szewczuk & Prinsloo 2010), the country's wind energy sector is growing exponentially. While renewable energy not only provides a 'cleaner' energy source, the REIPPPP has welcomed foreign investment and local economic relief (Eberhard et al. 2014; Baker & Wlokas 2015).

Despite this, renewable energy is not without environmental impacts. Wind energy developments, in particular, have been scrutinised for their negative effects on avifauna, especially birds (Kuvlesky et al. 2007; Rydell et al. 2012; Gove et al. 2013). The risk of collision with WEF infrastructure is the most obvious impact, and while it remains a threat, several indirect impacts also affect bird populations (Barrios & Rodriguez 2004; Marques et al. 2014; Dai et al. 2015; Wang et al. 2015). Wind farm related impacts are now generally divided into four categories: (1) collision risk, (2) habitat loss (3), displacement and (4) barrier effects (Drewitt & Langston 2006; Saidur et al. 2011).

A number of studies have suggested that wind turbines are the cause of considerably less bird fatalities than other anthropogenic structures (Calvert et al. 2013; Hovick et al. 2014; Wang et al. 2015). Some prominent case studies in Spain, the United States and Norway have, however, also highlighted the impact of wind turbines on avian populations (Smallwood & Thelander 2008; de Lucas et al. 2012; Dahl et al. 2013). The repercussions of these losses are reflected in declining breeding success, as Dahl et al. (2012) recorded amongst White-tailed Eagles (*Haliaaetus albicilla*) within and close to the Smøla Wind Farm in Norway. While these have been isolated cases, the threat is ubiquitous. Varying estimates of the cumulative bird collisions in the United States (Manville 2005; Sovacool 2012; Loss et al. 2013; Smallwood 2013) demonstrate a high degree of data inconsistency, which also casts doubt over the reliability of impact assessments.

Collision risks, though, are dictated by a number of factors (Barrios & Rodriguez 2004; de Lucas et al. 2008; Dai et al. 2015), which are generally grouped into species-specific, site-specific and wind farm-specific (Marques et al. 2014). These factors range from a species' morphology, phenology and flight behaviour to a site's topography and climate, as well as the design and configuration of the wind turbines (Marques et al. 2014). Collision fatalities are governed by an interactive relationship between a variety of these factors (Barrios & Rodriguez 2004; Hoover & Morrison 2005; Morinha et al. 2014). Long-lived species, with low reproductive rates and slow maturity, are particularly susceptible to wind turbines (Whitfield et al. 2004; Dahl et al. 2012). This is particularly true for raptors, who have been at the centre of most bird collision risk assessments (Hoover & Morrison 2005; Telleria 2009; Carrete et al. 2012; Ferrer et al. 2012; Bellebaum et al. 2013; Hernández-Pliego et al. 2015).

Research has largely been focussed on collision-induced mortalities and their impacts, due to the relatively easy quantification thereof (Rydell et al. 2012). Some authors have, however, proposed that habitat loss, displacement and barrier effects may inhibit some species' breeding performance more than the actual loss of breeding individuals (Kuvlesky et al. 2007; Zeiler & Grünschachner-Berger 2009; Pearce-Higgins et al. 2012; Hovick et al. 2014). Much like the direct impacts associated with collisions, the adverse effects associated with avoidance behaviour and habitat loss vary between site, wind farm and species (Madders & Whitfield 2006; de Lucas et al. 2008; Campedelli et al. 2013). A multi-site and multi-species study conducted by Pearce-Higgins et al. (2012) suggests that displacement during construction may have the most significant impact on breeding populations. While Campedelli et al. (2013) also made observations that support this, other authors have found little to no evidence of significant displacement within and around wind farms (Pearce-Higgins et al. 2012; Hatchett et al. 2013; Hale et al. 2014; Hernández-Pliego et al. 2015). Responses, both negative and positive, are largely associated with changing vegetation structure, and vary between species, depending on their foraging habits (Drewitt & Langston 2006; Rabin et al. 2006). While increased food availability within a wind farm may benefit some birds, it also magnifies the collision risk (Gove et al. 2013).

As more evidence of wind-energy-related impacts, and their complex and cumulative nature is emerging, the need and potential for further research and mitigation is becoming increasingly apparent (Wang et al. 2015). This is especially true for rapidly expanding wind energy industries, such as South Africa's. With legislation and policies in place to ensure the effective mitigation of such impacts (National Environmental Management Amendment Act No. 62 of 2008), it is essential to further our understanding of them. In 2010, the Birds and Wind Energy Specialist Group (BAWESG), and the Birds and Wind Energy Forum (BAWEF) were convened by BirdLife South Africa (BLSA) and the Endangered Wildlife Trust (EWT) in an attempt to address these issues. These attempts have included the compilation of the recently revised Birds and Wind Energy Best Practice Guidelines (Jenkins et al. 2015) and the Avian Wind Farm Sensitivity of South Africa (Retief et al. 2011), as well as the Department of Environmental Affairs' (DEA) Environmental Impact Assessment (EIA) Guideline for Renewable Energy Projects (DEA 2015). Two monitoring techniques recommended by Jenkins et al. (2015) are direct or visual, and radar observations.

The use of the latter first emerged in the 1940's, when Lack and Varley (1945) observed mysterious radar signals or 'angels', before concluding that they were, in fact, birds. Since then, radar technology has been applied to detect, monitor and quantify flight patterns of birds and other avifauna (Eastwood 1967; Bruderer 1997; Gauthreaux & Belser 1998). What is now known as radar ornithology, has become an effective and invaluable conservation and research tool (Gauthreaux & Belser 2003).

The first application of radar in a conservation context has been attributed to Gauthreaux (1985), who used a mobile marine surveillance radar unit to assess collision risks at power lines in California. Since the commercialisation of avian radar systems in the late 1990s (Nohara et al. 2007), their use in environmental assessments has grown considerably (Nohara et al. 2011). These have largely involved marine surveillance radars (X- and S-band), due to their affordability, availability and versatility (Deng & Fredericks 2001; Mabee et al. 2006; Villegas-Patraca et al. 2014).

Technologies vary based on research needs or management strategies. Small, low-powered, Doppler-traffic radars have allowed us to measure the ground speed of short-range avian targets (Evans & Drickamer 1994, Brigham et al. 1998). Meanwhile, military tracking radars have been used to extract information on the altitudinal and density distribution of targets (individuals or flocks), by tracking targets within the radar's scan volume and plotting the trajectory in three dimensional space (Williams 1984; Bruderer et al. 1995). Moreover, high-powered, long-range surveillance radars are able to quantify bird movements at distances ranging between 80 km and 240 km (Gudmundsson 1993; Gauthreaux & Belser 1998; Diehl et al. 2003; Desholm et al. 2014). With an increase in range of detection, radar usually compromises other attributes, such as minimum altitude and range resolution (Millikin 2005).

Extensive Weather Surveillance Radar (WSR) networks, such as that of the United States' National Weather Service (NWS), have been used to great effect to monitor and quantify the distribution, abundance and movements of migratory bird species, on a large scale (Larkin 1991; Russell et al. 1998; Black & Donaldson 1999; Larkin et al. 2002; Diehl et al. 2003; Bonter et al. 2009; Randall et al. 2011; Buler et al. 2012). In Europe the Operational Programme for the Exchange of Weather Radar Information (OPERA) network has been used to a lesser extent (van Gasteren et al. 2008; Dokter et al 2011). With the establishment of the European Network for Radar Surveillance of Animal Movement (ERAM) in 2014, the OPERA radars are set to be employed comprehensively, to monitor and study avian movements across the continent (Shamoun-Baranes et al. 2014).

Nohara et al. (2007) have grouped technological advances in radar ornithology into manual target extraction (before 2000), automated target extraction (after 2000), and multi-sensor integration and fusion (after 2005). Radars' relative inability to distinguish between birds and other flying biological targets (i.e. bats and insects) or clutter (Eastwood 1967), prompted the latter development. It has, however, become possible to write target-specific algorithms, which discriminate targets based on groundspeed, target size (signal intensity) and other variables (Bruderer & Boldt 2001; Bachmann & Zrnic 2007; Schmaljohann et al. 2008; Plonczkier & Simms 2012). Although such algorithms can potentially distinguish species or, at least, groups with similar flight behaviours, less discrete overlaps lower the confidence levels of accurate target identification (Lilliendahl et al. 2003).

In order to address this shortcoming, wing-beat frequencies of certain bird species have been used as an identification signature (Zaugg et al. 2008). While relatively effective, this technique has similar constraints to the extraction of signature bird tracks (Bruderer et al. 2010). More commonly, radar has been supplemented by direct visual or other digital monitoring techniques (e.g. satellite telemetry, thermal imaging, radio telemetry, microphones, etc.), in an attempt to accurately identify species (Millikin 2001; Bigger et al. 2006; Gauthreaux & Livingstone 2006).

South Africa’s exposure to radar ornithology has been very limited, and while Jenkins et al. (2015) recommend the use thereof for priority species, the costs associated with its employment often deters potential clients. Considering the country’s rapidly developing wind energy sector and its impacts on birds, an accurate monitoring protocol needs to be in place, to ensure the effective mitigation of these impacts. Despite its limitations, the unbiased and visibility-independent observations that radar provides, has shown to be invaluable for both research and assessments. While ground-based observations offer another dimension, their inaccuracies make them an unreliable primary monitoring method (Harmata et al. 1999; Cooper & Blaha 2002; Bigger et al. 2006). Out of the 846 bird species in the country, 105 have been assigned priority scores based on their vulnerability to wind energy developments (Retief et al. 2011). Boasting the two highest scores are the Bearded Vulture (*Gypaetus barbatus*) and the Cape Vulture (*Gyps coprotheres*) [Retief et al. 2011], the latter being this study’s primary subject. Hence, this study aimed to assess the accuracy of visual observations relative to radar observations, with an emphasis on Cape Vultures.

2.2. Study Site

Based approximately 30km west of Komga (-32.577°, 27.888°) within the Amathole District Municipality in the Eastern Cape Province, the study sites were selected based on the prospective development of a WEF, as well as the occurrence of Cape Vultures. A total of 17 land parcels in that area have been secured by Windlab Developments South Africa (Pty) Ltd (Windlab hereafter) with the objective of developing the Umtathi Emonyeni WEF.

Three radar placement sites (T1, T2 and T3) were established on three separate land parcels along the R63 between Bisho (-32.849°, 27.438°) and Komga (-32.577°, 27.888°) [Figure 1.1]. These were selected based on the landscape's capacity to maximise coverage of the radar scan volume.

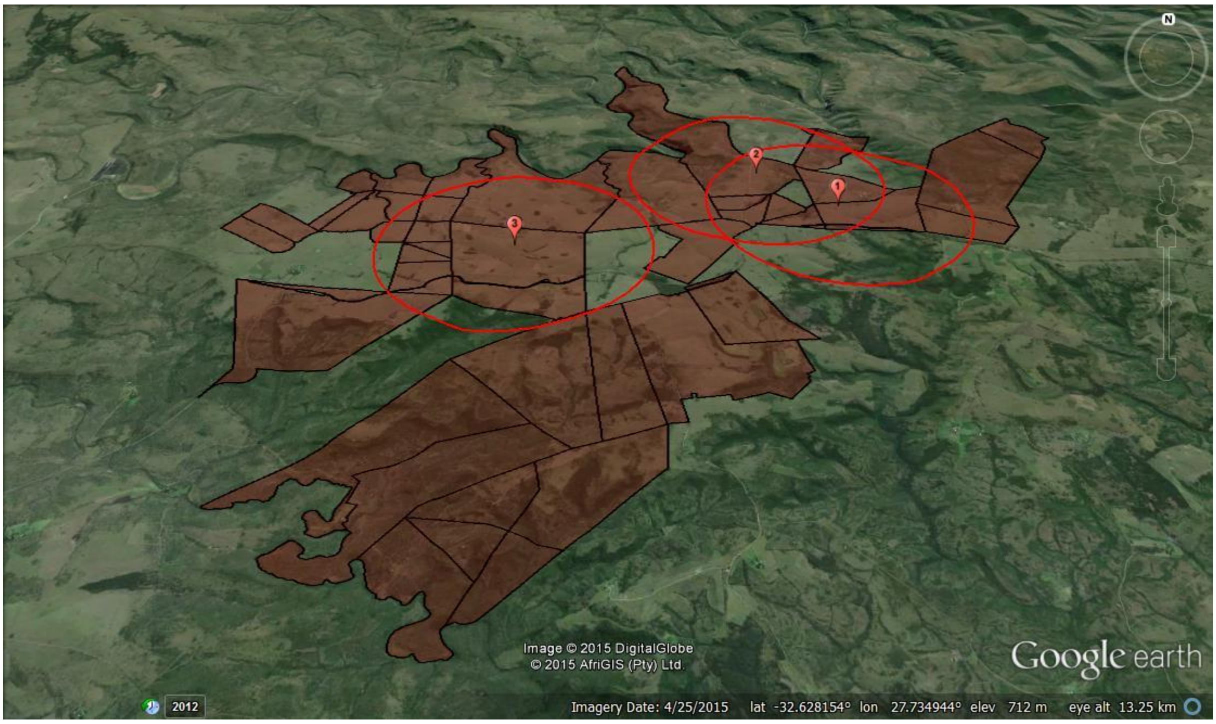

Figure 3.1: Land parcels secured for the proposed Umtathi Emonyeni WEF and the radar survey points (numbered accordingly), each surrounded by a 3km radar radius (red line).

The vegetation at the three sites ranged from savannah habitats in the east, dominated by *Acacia karoo*, to open grasslands interspersed with dense *Eucalyptus* and *Acacia* forest patches in the western parts. According to Mucina and Rutherford (2006) our study area's vegetation structure is a mosaic of Bhisho Thornveld, Amathole Montane Grassland and Eastern Valley Bushveld. Due to the intensive rearing of livestock and the production of fodder crops, the area is scattered with artificial water bodies. Meandering through the mountainous landscapes, the Kubusi

River traverses T2 on the site's western edge and eventually joins the Kei River in the north. These perennial rivers have carved steep gorges into the region's geology, which provides ideal breeding habitats for cliff-nesting vulture species, such as *G. coprotheres*. The closest breeding colony of Cape Vultures is known as the Vumenjani colony (-32.380°, 27.880°), and is located approximately 20km north-east of the study site.

2.3. Study animal

The Cape Vulture or Cape Griffon is an Old World vulture species (Lerner & Mindell 2005) endemic to southern Africa (Mundy et al. 1992).

These birds' body length generally ranges between 100cm and 118cm, while their wing span can reach 2.3m (Sinclair et al. 2011). The adults' primarily cream-coloured plumage is complimented by a dark tail and flight feathers. Silver-white secondary feathers and black alulae make up the underwing, while the skin of their exposed head and neck appears greyish blue. A black beak and yellow eyes complete their facial appearance. Juveniles are slightly darker, with more brownish eyes and a red neck.

Vocalisation amongst Cape Vultures is rare and, supposedly, restricted to breeding colonies or roosts (Sinclair et al. 2011). These vocalisations can be described as a variety of cackling, grunting and hissing.

A single egg is usually laid (Piper et al. 1981; Mundy 1982) somewhere between April and June (Boshoff & Currie 1981; Robertson 1986; Borello & Borello 2002). It takes the egg approximately eight weeks to hatch, followed by an estimated 140-day nestling stage (Piper et al. 1981; Robertson 1986). Most juveniles leave the colony after fledging in November/December, which coincides with the start of the next breeding season (Piper et al. 1981; Mundy 1982).

G. coprotheres is a scavenger of ungulate carrion, like most vulture species in the region (Mundy 1982). The land use transformation to agriculture across its range, has made the Cape Vulture increasingly dependent on livestock (Robertson & Boshoff 1986; Komen & Brown 1993).

Today, Cape Vulture breeding colonies are largely concentrated within two regions (Mundy et al. 1992). One comprises northern Transvaal (Benson et al. 1990;

Whittington-Jones et al. 2011), while the other encompasses western KwaZulu-Natal (Brown & Piper 1988), across the Lesotho highlands, and the former Transkei in the Eastern Cape Province (Mundy et al. 1992; Boshoff et al. 2009). Literature suggests that the vast majority of the global population is confined to South Africa and Lesotho (Piper 1994, Botha et al. 2012), but relic colonies do still exist in Zimbabwe, eastern Botswana (Borello & Borello 1987; Borello & Borello 2002; Botha et al. 2012), and northern Namibia (Brown 1985; Bamford et al. 2007).

The species has been studied extensively since the 1950s, which has warranted substantial conservation action (Paterson 1952; Jarvis et al. 1974; Mundy et al. 1980; O'Connor 1980; Mundy et al. 1992). Despite this though, a global decline has been observed since the beginning of the 20th century (Ogada et al. 2012). McKean and Botha (2007) have suggested that the local population in eastern South Africa, has suffered an up to 70% decrease since 1990. The threats that have been contributing towards such alarming losses, range from habitat loss, collisions with wires and cables, carrion contamination, electrocutions, and unsustainable harvest for traditional medicine (Boshoff & Anderson 2006). The species was already described as 'vulnerable and threatened' in the first publication of the South African Red Data Book for Birds (Siegfried et al. 1976). The Cape Vulture's status has been uplisted to locally 'endangered' in the latest edition of the Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland (Taylor et al. 2015). Upon review of global Cape Vulture population trends, Ogada et al. (2015) have suggested that its past and present decline warrants a 'critically endangered' status (IUCN 2012). While sufficient evidence for such an 'uplisting' was lacking, the International Union for the Conservation of Nature (IUCN) recently approved a status adaption from 'vulnerable' to 'endangered', following an assessment by BirdLife International (BirdLife International 2015). Despite its relative discontinuity, unpublished data from 2013 estimate the global breeding population of Cape Vultures to now be under 3000 pairs (Wolter et al. 2014).

Of an estimated total of 2000 individuals in the Eastern Cape Province, the majority (~ 630 breeding pairs) are confined to the eastern sectors of the province (Boshoff et al. 2009). Active breeding colonies and regular roosts are located within or in close proximity (<50km) to the borders of the former Ciskei and Transkei (Boshoff et al. 2009).

2.4. Methods and Materials

2.4.1. Visual Monitoring

A vantage point (VP) was established at least 100m from its corresponding radar placement site (VP1: -32.57670°, 27.78832°; elevation: 664m; VP2: -32.56123°, 27.76842°; elevation: 703m; VP3: -32.59330°, 27.71026°; elevation: 741m). Between November 2014 and June 2015, five sampling replicates were completed. One replicate lasted a total of 12 days, with four days dedicated to each site. VP observations were conducted, two hour at a time, with a cumulative monitoring duration of 12 hours (06:00 – 18:00) per site.

VP selection was based on accessibility, observable water bodies (if available), and maximum coverage of radar scan volume.

Bushnell 10×42mm binoculars and Sinclair et al. (2011) aided in the species identification process, while a cross-platform desktop Geographic Information System (GIS) [QGIS 2.6 Brighton] was employed to plot the birds' movements. VPs and radar placement sites served as reference points, as well as Google Earth™ imagery. Species name, flight direction, time, flight height, flight behaviour, cloud cover, visibility and precipitation comprised the list of variables record during VP monitoring. Movements were illustrated as multi-jointed lines or polygons. Flight behaviours ranged from 'direct commuting' (gliding or flapping) to 'actively hunting', 'thermal soaring', and 'perching'. Targets were allocated to one of three height classes: <30m, 30m – 150m, and >150m. These values represent the general span rotor-swept area (RSA). Collected data were transcribed to a Microsoft Office Excel, which included the longitudinal and latitudinal coordinates for each plotted point. Movements of Cape Vultures, as well as 29 other priority species were recorded (Appendix). These species were selected according to their inclusion on the Avian Wind Farm Sensitivity Map for South Africa (Retief et al. 2011), and their occurrence at the site based on data from the Southern African Bird Atlas Project. This inclusion was based on each species' structural and behavioural traits, and conservation status (Retief et al. 2011).

2.4.2. Radar Monitoring

The EchoTrack™ Omni-directional Radar-Acoustic sampling system consists of a 25kW, 3cm wavelength surveillance Raccal Decca BridgeMaster E, with a 1.8m X-band antenna, which is fitted on a customised Venter© Kiosk Trailer (overall height: 2585mm, overall length: 3205mm, overall width: 2000mm). The antenna is modified to provide coverage of target height in addition to range and azimuth (Millikin & Buckley 2001), and is connected to a Sigma Engineering RSi 3000 radar digitising and recording system (Millikin 2001). With a range resolution of 7.5m, an angle resolution of 0.5°, and a height accuracy of 15m, the radar capture volume included a 2–3km radius around each placement, with a maximum height of 1950m in altitude for a total scan volume of 31.62km^3 during each sample. The system is powered by a Honda® EU30is inverter generator.

With the unit facing true north, to prevent any considerable offset, coordinates for each site were recorded at the tip of the trailer and marked.

Radar sampling regimes at each site spanned from midday on Day1 through to sunset on Day 3 and from sunrise to sunset on Day 4. Regimes were only interrupted for refuelling and scheduling purposes or weather-related risks, i.e. electrical storms. This would provide us with sufficient data on both the diurnal and nocturnal movements of priority species.

2.4.3. Observation confidence

Using the EchoTrack software, the flight path of each airborne target was defined by a set of consecutive track points (geographic coordinates with corresponding heights above ground, recorded every 1–3s for every tracked target). The radar separated aggregations of birds into the unique tracks of each individual.

All flight path information was collated in a database where radar tracks were matched with corresponding visual observations based on congruence in time, location and direction of flight. Species identifications were assigned to radar tracks using the database and ranked in confidence (in the assignment of species) where a bird within 100s and 100m, flying in the same direction was 99% (i.e., observer said NE and radar-derived direction was between 0 and 90°), versus a bird within 300s and 300m and the same direction which was 95%, and 500m and 500s which was 80%. All unmatched visual observations were reviewed in the database and where only one radar flight path was possible, the species identification was assigned assuming the observer was delayed in recording the individual or was confused in the location. Otherwise, the visual observation could not be matched so the visual and radar flights were left as unmatched.

Information from this matching was used to develop the algorithm to identify Cape Vultures from radar flight paths without a corresponding visual observation. Radar-determined flights are first separated into birds (not manmade objects, bats or insects) by size and speed; then further identified as Cape Vultures from other birds by size and speed.

2.4.4. Distance and time accuracy

The data obtained from the process described in 1.4.3. were used to assess the temporal and positional accuracy of our visual observation. Mean differences in both distance and time between matched visual and radar tracks of Cape Vultures and other priority species were then calculated. After testing the equality of the variances of these samples, a two-sample t-test assuming unequal variance (Microsoft Excel 2013) was performed, comparing the means difference in time and distance between Cape Vulture tracks and those of other observed species.

2.4.5. Flight height and range accuracy

Using the height data obtained from the radar, the altitudinal accuracy of our visual observations was determined. As mentioned in 1.4.3. the height of a target during VP observations was assigned to one of three brackets, namely less than 30m, between 30m and 150m, and above 150m. The upper and lower limits represent the relative extent of the rotor-swept area (RSA).

A ‘1’ was assigned to accurate observations and a ‘0’ for inaccurate estimates, which allowed the proportion of accurate and inaccurate observations to be determined – for Cape Vultures, and other priority species. These data were then arranged in a two-way table, before completing Pearson’s chi-squared test to test for goodness of fit and independence (Microsoft Excel 2013). Both the flight height, and the range (or distance of target from radar) measurements were grouped according to the accuracy (1 or 0) of that particular point for all observations, and then compared using a Mann-Whitney U-test (STATISTICA 12). Pooled inaccurate height estimations were also categorised according to the perceived bracket, in which they were placed. The median for each of these categories was determined to examine how perceptions differed amongst inaccurate observations.

Moreover, the degree of inaccuracy (in metres) was determined by subtracting the height recorded by the radar from the nearest bracket value of the matched visual observation. These differences were then used to establish the mean degree of inaccuracy for the Cape Vulture sample, as well as for the remaining observations. Another two-sample t-test assuming unequal variance was performed to compare these sample means (Microsoft Excel 2013). The degree of inaccuracy was also applied in two nonparametric correlation analyses, in order to establish its relationship with both target height and range (STATISTICA 12).

Flight tracks (both radar and visual) recorded within the RSA were extracted from the database, in order to analyse the difference in risk assessment amongst visual and radar observations.

Due to the fact that each visual observation was only matched with one corresponding radar point (a track consisting of several points), the flights at risk (or within the RSA) may be an underestimation. For that reason it was necessary to determine the height of the start- and end-point of the respective tracks. By calculating the mean of these two values for each track, it was possible to see whether the track, at any time, passed through the RSA.

2.5. Results

Out of the total 149 visual observations made, 99 (or 66.4%) were assigned corresponding radar tracks with varying degrees of confidence. The remaining 35.9% were left unmatched. A combined total of 16 priority species were recorded, which included the Cape Vulture. The radar tracks of 12 of those 16 species (n = 58) were confidently verified (see 1.4.3.). The only two visually observed Blue Cranes (*Anthropoides paradiseus*) and five Denham’s Bustards (*Neotis denhami*) were paired with corresponding radar tracks (Figure 1.2). A disproportionately high ratio (1.14; n = 42) of successfully matched tracks were, however, extracted for Cape

Vultures (Figure 1.2). The ratio is such, because where the observer recorded one sighting (regardless of abundance), the radar generated a single track for an individual bird – so, several radar tracks may be assigned to the same visual observation.

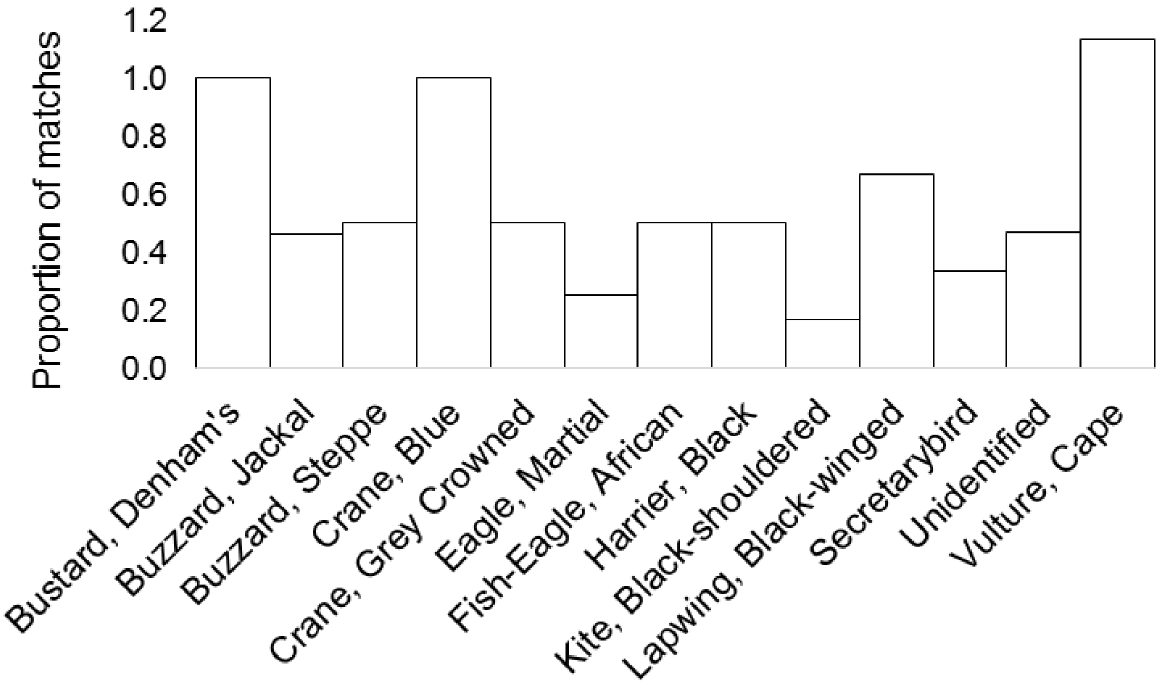

Figure 1.2: Proportion of successfully radar-verified visual observations for each species (including unidentified targets).

Half of the Cape Vulture observations were identified with 99% confidence, while less than 20% of tracks of the other observed species warranted the same level of confidence (Table 1.1). As Table 1.1 reveals though, proportions were almost identical between Cape Vultures (0.48) and other species (0.47) for tracks identified with 95% certainty. The majority of other priority species (50%) were visually confirmed with very low confidence, whereas only 2% of Cape Vulture tracks met the same criteria (Table 1.1).

The mean difference in distance between all matched radar and visual tracks varies significantly ($p < 0.01$) between Cape Vultures (157.9m; SE 25.6m) and the other priority species (337.2m; SE 43.6m), while no such significance was observed across confidence levels (Table 1.1). Similar trends were recorded for time delays between visual and radar observations. Visually assessed Cape Vulture tracks were significantly ($p < 0.01$) less delayed (65.0s; SE 16.3s) than those of other species

(146.8s; SE 18.0s; Table 1.1). This delay, however, was only significant overall and not specific to a confidence level (Table 1.1). Table 1.1 also indicates that, on average, the positional gap between the most positively (99%) corresponding points for other species was considerably larger (380.5m; SE 194.4m) than the prescribed threshold of 300m. High confidence levels were assigned to such matches, due to the absence of conflicting alternative tracks.

Table 2.1: Comparisons between Cape Vulture (G. coprotheres) and other priority species across the confidence levels of paired radar and visual observations, and the mean temporal and horizontal delays separating them. A double asterisk indicates a highly significant difference (p < 0.01) between the means of the two taxonomic groups for the respective variable.

	Proportion matched		Mean difference in distance (m)		Mean difference in time (s)	
Confidence level (%)	*G. coprotheres*	Other species	*G. coprotheres*	Other species	*G. coprotheres*	Other species
99	0.50	0.14	102.1	380.5	22.8	18.5
95	0.48	0.47	171.6	268.7	90.5	128.9
80	0.02	0.40	1059.0	402.8	442.0	212.4
Total	1.14	0.50	157.9**	337.3**	65.0**	146.8**

Having used the matched radar recordings as reference points, Figure 1.3 illustrates the accuracy of visual height estimations for Cape Vultures (a) and the other species (b) recorded. Barely a quarter (23.8%) of Cape Vulture observations were accurate, while more than half (53.9%) of other observations fell within the designated height bracket. Pearson's chi-squared test, however, revealed that taxonomic differentiation and accuracy were not significantly related ($p = 0.941$; $\chi^2 = 0.01$). The extent of the inaccuracies or the distance from the closest bracket boundary between Cape Vulture and other observations, were not substantial ($p = 0.512$). Cape Vulture height estimates were misplaced by 176.2m (SE 44.2m), on average, and the other observations by 146.0m (SE 40.1m). Most accurately assessed Cape Vulture flights (60.0%) were located within the RSA at that time (Figure 1.3a). The vast majority (96.3%) of other species' flight tracks were accurately estimated below the RSA (Figure 1.3b). Due to the wide range of recorded heights, a logarithmic scale was applied to enhance the graphical representation for this dataset. Visual observations of Cape Vultures placed 69.1% within the RSA, where only 21.4% of the corresponding radar points were at risk. The opposite was observed for other bird species, with visually assessed flights at risk (9.8%) falling short of their radar counterparts (21.6%).

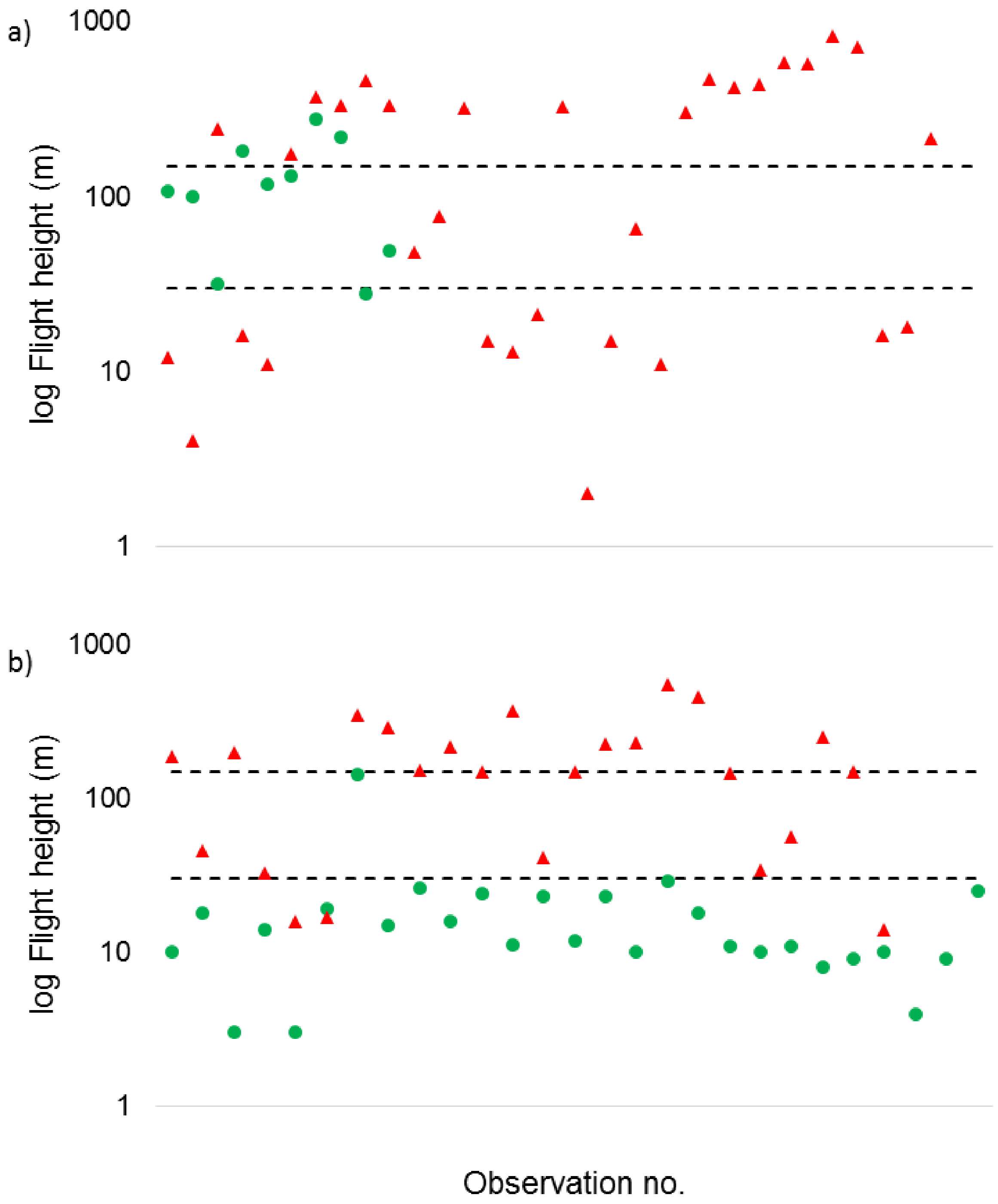

Figure 1.3: The vertical distribution of inaccurate (red triangles) and accurate (green circles) Cape Vulture (a) and other priority species (b) observations, with reference to the RSA boundaries (dashed lines).

The magnitude of Spearman's rank correlation coefficient ($r = 0.856$) in Figure 1.4a provides evidence for the significance ($p < 0.001$; $n = 57$) of the relationship between the degree of inaccuracy and the target's height. Differences in flight height ($p < 0.0001$) and range ($p = 0.022$) between accurate and inaccurate observations were both significant. However, the difference in range between Cape Vultures (median = 569m) and other species (median = 447.5m) was not substantial ($p = 0.093$). Median flight heights of Cape Vultures (125.1m) and other priority species (24.5m), on the other hand, differed substantially ($p = 0.024$). Figure 1.4b exhibits the positive relationship between the range (distance of target from radar) and the extent of the inaccuracy, which a Spearman's rank correlation coefficient of 0.558 ($p < 0.001$; $n = 57$) deems to be very significant. This implies that the further the target is away the more difficult it is to assess its height visually.

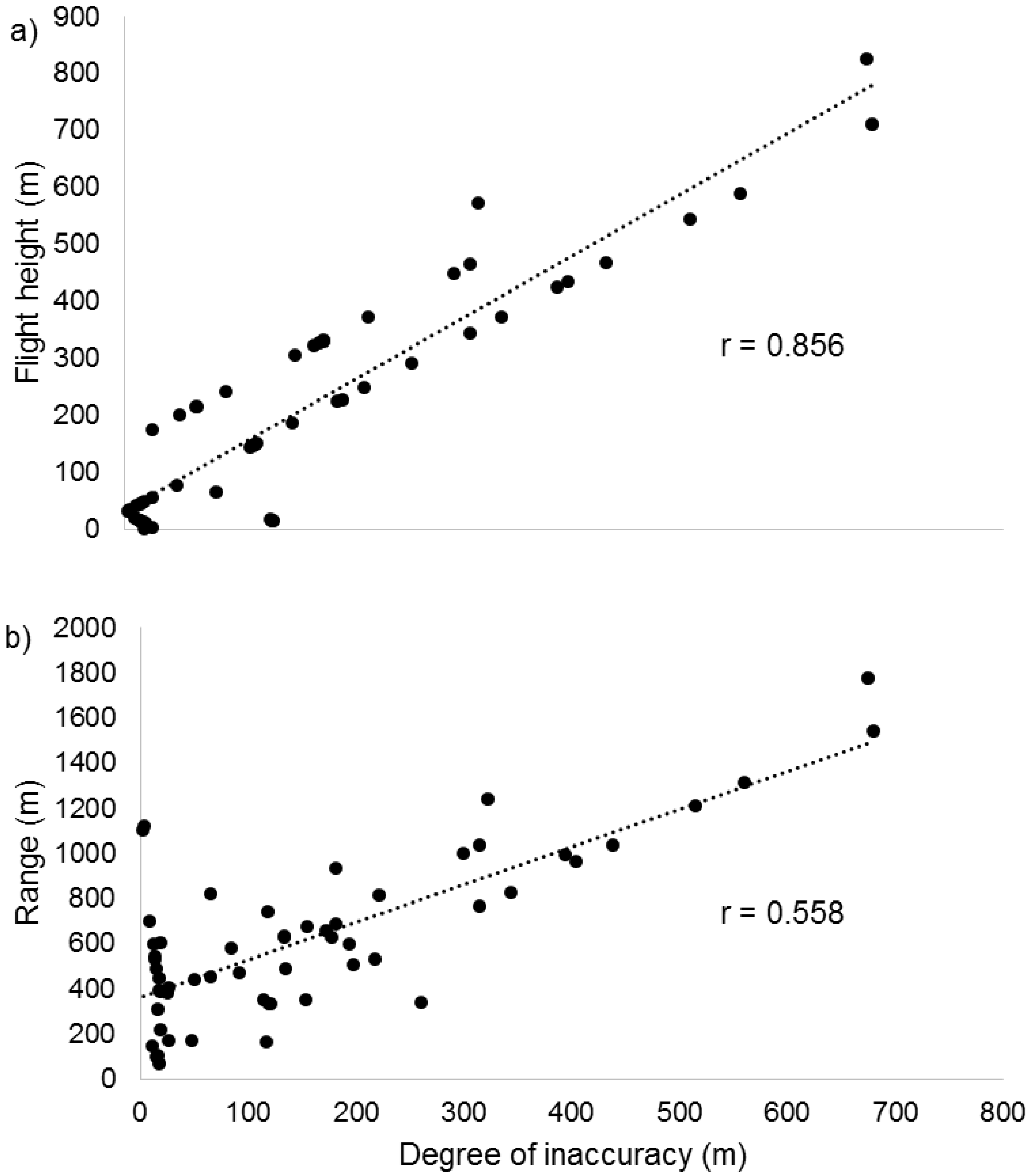

Figure 1.4: Illustration of (a) the linear relationship between the degree of inaccuracy of visual observations and the height of the target, and (b) the linear relationship between the degree of inaccuracy of visual observations and the distance of the target from the radar (range), including the Spearman's rank correlation coefficients (r).

Inaccurately perceived targets allocated below 30m had a median value of 168.5m (n = 26), while those falsely estimated to be occupying the RSA produced a median of 200m (n = 27). The four misplaced observations above the RSA had a median height of 16.5m. Including the accurate observation these medians adapt to 29.0m (<30m; n = 53), 125.1 (30m – 150m; n = 34) and 66.0m (>150m; n = 7), respectively. Analyses of false negatives concluded that 14% of all inaccurate visual observations were, in fact, accurate. The mean difference in height between the start- and end-point for all matched tracks was 20.2m (SE 6.6m; n = 113).

2.6. Discussion

Considering, not only the large proportion of Cape Vulture observations matched with high confidence, but also their relatively narrow delay margins in time and distance, it has to be assumed that Cape Vultures are either easily observable or that an observer-bias exists. The latter would be a logical assumption, since the Cape Vulture represented the primary subject of this study, and could have perhaps (albeit subconsciously) attracted more attention from the observer. Since their movements are largely reliant on thermal winds (Jarvis et al. 1974, Bohrer et al. 2012) and thus directionally variable, vulture (or large raptor) flights are difficult to assess visually. This reliance on thermal winds translates into principally circular movements, which in turn, increase the probability of a visually observed track overlapping with its corresponding radar track. Cape Vultures also generally forage in larger numbers (Mundy et al. 1992), which further increases the chances of a successful track pairing. This behavioural trait also contributes towards a larger sample size, which creates a sampling bias. At the same time such foraging and flight behaviour makes the species' movements extremely difficult to track visually. Considering this, the accuracies in time and distance intervals between radar visual observations for Cape Vultures could be misleading.

Such observational biases are, however, countered by the fact that the median flight height of the Cape Vultures (125.1m) is considerably larger than that of other species (24.5m) at the study site. This is supported by the positive linear relationship between flight height and degree of inaccuracy, and between range and degree of inaccuracy (Figure 1.4). For both flight height and range, Cape Vultures displayed higher values than the other species – the latter variable is, however, coincidental. Contrasts between Cape Vultures and other species are relatively unfounded though, due to the diversity in flight behaviour and morphology amongst the other priority species. For example, a Martial Eagle (*Polemaetus bellicosus*) will be more similar to the Cape Vulture, morphologically and behaviourally, while a species such as the Black-winged Lapwing (*Vanellus melanopterus*) is a medium-sized, insectivorous bird, which primarily occupies the lower air spaces (Sinclair et al. 2011) – combining the datasets of these two species will, thus, have a certain statistical counteractive effect.

Nevertheless, the median height recorded for Cape Vultures, coupled with the inverse relationship between accuracy and flight height (Figure 4a), makes these birds, difficult targets to assess visually. With differences in time and distance between matched radar and visual tracks ranging from 0s to 474s and 2m to 1405m, respectively, the room for error is extensive. The confidence margins applied in this study are relatively wide, and while inaccuracies are virtually unavoidable, their minimisation is crucial to avian assessments. Accurate height perception is particularly relevant at WEFs, because of the extent of the RSA, and while devices such as range finders can be utilised during avian assessments, technologies such as radar provide unmatched accuracy. Margins for error are narrow when trying to mitigate the collision risks at a wind farm, as several studies have reported localised mortalities.

De Lucas et al. (2012) reported one of the highest ever vulture mortality rates per turbine across 13 different wind farms in Spain. Out of the 296 turbines, more than 200 claimed no collision victims, while a maximum of four fatalities was recorded at less than ten turbines (de Lucas et al. 2012). These highly significant differences in mortality rates between individual turbines are supposedly the result of local wind currents and topographical features, which is also supported by Barrios and Rodriguez (2004), and de Lucas et al. (2008). The placement of individual turbines is thus vital in mitigating collision risks at WEFs.

Poor placement of wind turbines not only has a potential impact on local bird populations, but can also have economic repercussions for developers, as certain legal frameworks demand financial remuneration for avian mortalities, or even the decommissioning or replacement of certain turbines. One such event occurred recently at the Altamont Pass Wind Resource Area (APWRA) in California, where Altamond Winds Inc. is set to shut down operation of its more than 800 turbines in the Altamond (Quirós 2015). According to an article by Quirós (2015), these turbines have been responsible for 67 Golden Eagle (*Aquila chrysaetos*) deaths between

2004 and 2014. Smallwood and Thelander (2008) recorded an estimated 56 Golden Eagle mortalities at 1526 turbines within the APWRA, between 1998 and 2002.

A cross-platform GIS for visual monitoring has not been applied in related studies, which makes it impossible to draw any direct comparisons. Some previous studies have, however, already highlighted the inefficacy of visual surveys (Cooper & Blaha 2002; Bigger et al. 2006). Cooper and Blaha (2002), and Bigger et al. (2006) estimated a 23% and 20% detection probability, respectively, for audio-visual surveying. The detection probability for radar surveying, in contrast, amounted to 76% (Bigger et al. 2006). A similar study by Harmata et al. (1999) concluded that radar detected 12 times as many birds as visual observers did.

While a cross-platform GIS allows the observer to place targets relative to landscape features using Google Earth images, as well as extract the track's coordinates, distance and height perception still influence the accuracy. Various other observer-based factors also affect the accuracy of observations. These include fatigue, motivation and experience, while environmental factors such as visibility also impact the quality of visual surveys. Visual surveys in this study consisted of two-hour shifts, whereas Jenkins et al. (2015) recommend three-hour stints. The shift length was reduced in this study, due to a lacking labour force and in an attempt to further optimise accuracy.

Substantial mean differences in distance (262.7m), time (146.7s) and height (159.4m) between corresponding visual and radar observations underline the inaccuracy of visual surveys. With the availability of avian radar systems and the required operational expertise, avian impact assessments for particularly sensitive sites, should employ these technologies and skills. Avian radars are, however, still restricted and require augmentation through visual surveying for species identification (Harmata et al. 1999; Schmaljohann et al. 2008; Plonczkier & Simms 2012). Considering the expansion of wind energy and its spatial requirements, the recording of individual bird movements demands a high degree of accuracy.

In terms of bird morphology and flight behaviour, biometrics such as wing-loading (body mass/wing area) affect manoeuvrability, which declines with larger wing-loading (de Lucas et al. 2008; Rushworth & Krüger 2014). Cape Vultures have remarkably high wing-loading (Campbell 2015), increasing their risk of collision at wind farms. The visually confirmed median Cape Vulture track occupies the RSA, which further substantiates their vulnerability. Modelling analyses of Cape Vulture populations in the Maluti-Drakensberg Mountains have predicted population growth to fall by 1.4% per annum as a result of WEFs (Rushworth & Krüger 2014). Bearing in mind the Cape Vulture's deteriorating conservation status and its range restrictions, the survival of these birds is under siege.

South Africa's DEA and DoE, in conjunction with the Council for Scientific and Industrial Research (CSIR) have undertaken a strategic environmental assessment (SEA) with the aim of identifying renewable energy development zones (REDZ) [Rycroft 2015]. These zones were outlined based on their potential for renewable energy and span across almost 7% of the country. Two of these REDZs fall within the Eastern Cape Province and comprise more than 11% of its total extent. Following the latest round of the REIPPPP, 43% of all onshore wind energy projects procured, have been allocated to the Eastern Cape (DoE 2015). Having identified almost 20 000km^2 for renewable energy (primarily wind) development within the province, holding about a fifth of its global population (Boshoff et al. 2009; Wolter et al. 2014), the Cape Vulture could be facing a stern challenge to uphold this fortress.

2.7. Conclusion

Jenkins et al. (2015) state that one of the aims of pre-construction monitoring is to estimate the frequency at which birds move through the proposed RSA. The wide margins between visual and radar observations, documented in this study, affirm the need for perhaps a more stringent set of guideline, specifically applicable to the movement of South Africa's priority bird species at proposed WEFs. While visual monitoring remains a more cost-effective option for most developers, integrating and implementing technological conservation tools such as avian radar systems should be mandatory at particularly sensitive sites.

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CHAPTER 3

3. A Radar Study of Cape Vulture (*Gyps coprotheres*) Activity Patterns at a Proposed Wind Farm in the Eastern Cape Province, South Africa

Abstract:

With the accelerated development of wind energy in the country, South Africa's birds are confronted with another anthropogenic threat. Impacts on the Cape Vulture, in particular, are of great concern. Avian assessments are a prerequisite for the development of a wind farm. To ensure optimal mitigation, monitoring efforts have to be thorough and accurate. This study investigated the potential of employing visually supplemented radar monitoring for the assessment of activity patterns of Cape Vultures at a proposed wind farm in the Eastern Cape Province. The marine surveillance radar used in this research is able to provide parameters such as coordinates, flight height[1], flight speed, and flight direction for each individual target. An algorithm for automated target extraction was developed by visually verifying Cape Vulture radar tracks. Using this information, movement frequencies, as well as climbing rates and mean flight heights were analysed. Visually and radar observed movement frequencies yielded similar trends, with frequencies peaking around noon. Both climbing rate and mean flight height trends were also at their highest during the middle of the day. All visual observations fell within a seven to eight hour period, while radar-recorded Cape Vulture tracks stretched across a period twice as long. This study demonstrated the practicality of radar technology for avian assessments, as well as related research. Data collected through radar can improve the reliability of management decision-making, and mitigation strategies.

Keywords: activity, birds, Cape Vulture, mitigation, radar, wind energy

3.1. Introduction

South Africa's divergence from a primarily coal-dependent economy (EIA 2015) has been demonstrated by sizeable and globally competitive investments in the

[1] EchoTrack patent

development of renewable energy over the least three to four years (REN21 2013, 2014, 2015). This move was kick-started by 2003's White Paper on Renewable Energy in 2003 (DME 2003). The meteoric progression of the renewable energy sector is due to the success of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)[DoE 2012; Eberhard et al. 2014; Msimanga & Sebitosi 2014]. With the conclusion of the fourth bidding window in June 2015, a total of 92 projects have already been procured across all windows, with a total capacity of 6327MW (DoE 2015).

After it took South Africa a decade to install its first 10MW of wind power, the REIPPPP has procured a total onshore wind energy capacity of 3356MW since the first bidding window in 2011 (DoE 2015). This number falls just short of the halfway mark of the 9200MW-target for 2030 set in the Integrated Resource Plan (IRP), which was promulgated in 2011 (DoE 2011; DoE 2013). Providing not only cleaner energy, but also job creation, socio-economic growth and cheaper electricity (Eberhard et al. 2014; Baker & Wlokas 2015; DoE 2015), the expansion of the South African wind energy industry shows no signs of slowing down.

Regardless of this, the erection of wind turbines has come under scrutiny worldwide, because of the impact on avian populations (Kuvlesky et al. 2007; Rydell et al. 2012; Gove et al. 2013). Wind energy facilities (WEF) present a direct collision risk, while also causing displacement, barrier effects and habitat loss (Barrios & Rodriguez 2004; Drewitt & Langston 2006; Saidur et al. 2011; Marques et al. 2014; Dai et al. 2015; Wang et al. 2015).

Although evidence of the comparatively insignificant contribution of wind turbines towards collision-related bird deaths has been presented, the impacts cannot be underestimated (Martinez-Abrain et al. 2012; Calvert et al. 2013; Hovick et al. 2014; Wang et al. 2015). The Altamont Pass Wind Resource Area (APWRA) serves as a fitting example. Smallwood and Thelander (2008) recorded 56 Golden Eagle (*Aquila chrysaetos*) fatalities from 1998 to 2003, which for long-lived bird species (such as raptors) could be devastating on a local population scale. Evidence of a WEF inhibiting the breeding success of a species was presented by Dahl et al. (2012), who documented significantly less successful breeding attempts amongst White-tailed Eagles (*Haliaaetus albicilla*) within and close to the Smøla Wind Farm in Norway. These observed declines in breeding success were suggested to be a combination of both direct and indirect impacts (Dahl et al. 2012). Several studies have estimated cumulative collision-related bird fatalities in the United States, ranging from 10 000 to 573 000 (Manville 2005; Sovacool 2012; Loss et al. 2013; Smallwood 2013).

A wide spectrum of species-specific, site-specific and wind farm-specific variables drive collision risks (Barrios & Rodriguez 2004; de Lucas et al. 2008; Marques et al. 2014; Dai et al. 2015). Species' flight behaviour, morphology and phenology, a site's topographical features and weather patterns, as well as the configuration and design of wind turbines influence such risks (Marques et al. 2014). It is, however, difficult to pin-point a primary driver, as these influences are interactively linked (Barrios & Rodriguez 2004; Hoover & Morrison 2005; Morinha et al. 2014). Barrier effects, avoidance behaviour and habitat loss also affect avian communities varyingly across site, wind farm and species (Madders & Whitfield 2006; Kuvlesky et al. 2007; de Lucas et al. 2008; Zeiler & Grünschachner-Berger 2009; Pearce-Higgins et al. 2012; Campedelli et al. 2013; Hovick et al. 2014). Studies related to these impacts have thus also attained differential findings, with some species even reacting positively to the construction of a wind farm (Drewitt & Langston 2006; Rabin et al. 2006; Pearce-Higgins et al. 2012; Campedelli et al. 2013; Gove et al. 2013; Hatchett et al. 2013; Hale et al. 2014; Hernández-Pliego et al. 2015). Raptors have been amongst the most intensely studied birds at WEFs (Hoover & Morrison 2005; Telleria 2009; Carrete et al. 2012; Ferrer et al. 2012; Bellebaum et al. 2013; Hernández-Pliego et al. 2015), because their slow maturity and low reproductive rates make them particularly vulnerable to these developments (Whitfield et al. 2004; Dahl et al. 2012). In South Africa, a total of 105 bird species (13% of all species in South Africa) have been deemed particularly vulnerable to WEFs and are prioritised during avian assessments (Retief et al. 2011). Seven out of the eight vulture species occurring regularly in South Africa, have been included in this list (Retief et al. 2011). Boasting the highest priority scores are the two cliff-nesting vulture species – namely, the Bearded Vulture (*Gypaetus barbatus*) and the Cape Vulture (*Gyps coprotheres*). The vulnerability of these two species to wind energy developments has also been highlighted by Rushworth and Krüger (2014). They have predicted severe implications for the already dwindling population growth of both these species.

In order to fully assess and comprehend WEF-related impacts, the affected bird assemblages have to be well monitored. Over the years, a range of monitoring techniques have been developed and employed. Commonly, visual or direct surveys are conducted to collect information such as bird abundance and species identification (Mabee et al. 2005). Over the last few decades more technologies have been applied in bird surveying and amongst one of the most successful of those, are avian radar systems.

These systems have been commercially available since the late 20th century (Nohara et al. 2007). Following the discovery of radars' capacity to monitor avifauna (Lack & Varley 1945), the field of radar technology has steadily evolved into a valuable hub for the detection, monitoring and quantification of avian movements (Eastwood 1967; Bruderer 1997; Gauthreaux & Belser 1998; Gauthreaux & Belser 2003; Nohara et al. 2011).

Environmental impact assessments have been successfully augmented by the use of radar, ever since Gauthreaux (1985) used this technology to investigate the impact of a powerline on birds in California. Commercial units primarily consist of marine surveillance radars (X- and S-band), which are affordable, versatile and readily available (Deng & Fredericks 2001; Mabee et al. 2006; Villegas-Patraca et al. 2014).

Depending on the research aims, a variety of radar systems can be employed. Individual bird movements are best tracked using short-range military tracking or marine surveillance radars (Williams 1984; Bruderer et al. 1995), while migratory patterns are best observed with high-powered, long-range weather surveillance radars (WSR) [Gudmundsson 1993; Gauthreaux & Belser 1998; Diehl et al. 2003; Desholm et al. 2014]. An increase in a radar's range usually comes at the expense of its resolution and altitudinal capacity (Millikin 2005).

Large bird migrations have been studied extensively using the United States' National Weather Service's (NWS) network of WSRs, which is commonly known as Next-Generation Radar or NEXRAD (Larkin 1991; Russell et al. 1998; Black & Donaldson 1999; Larkin et al. 2002; Diehl et al. 2003; Bonter et al. 2009; Randall et al. 2011; Buler et al. 2012).

Some of the most monumental advances in radar ornithology are manual target extraction, automated target extraction, and multi-sensor fusion and integration (Millikin 2001; Millikin 2005; Nohara et al. 2007; Zaugg et al. 2008). While species identification remains one of radars' most significant limitations, it is possible to discriminate targets' signal intensity (size), groundspeed, as well as variables such as activity at certain wind speeds (Bruderer & Boldt 2001; Millikin 2005; Bachmann &

Zrnic 2007; Schmaljohann et al. 2008; Plonczkier & Simms 2012). What can essentially be described as an algorithm, has the potential to distinguish groups with similar flight patterns, but rarely individual species (Lilliendahl et al. 2003). Schmaljohann et al. (2008) investigated some issues with the quantification of migratory bird movements, using radar. One such issue was discriminating birds from insects, and although this was achieved using radar cross-sections and air speeds as discriminatory variables, the two taxonomic groups still overlapped to a certain extent (Schmaljohann et al. 2008). Such algorithmic distinctions, however, still rely on visual verifications.

Radar surveys are commonly complemented by direct observers and/or other digital monitoring techniques, such as thermal imaging, radio telemetry, satellite telemetry or acoustic recordings (Millikin 2001; Bigger et al. 2006; Gauthreaux & Livingstone 2006). Monitoring tools like these are an invaluable aid in environmental impact assessments (EIA), as well as research, and have afforded us the opportunity to explore the impacts of wind farms on birds in more depth. In countries, such as South Africa, where the wind energy industry is expanding at exceptional rates, the industry's environmental fraction is offered little time to adapt.

The National Environmental Management Amendment Act No. 62 of 2008 was the first legislative measure to ensure environmentally conscious renewable energy implementation in South Africa. Since then, non-governmental organisations (NGO), like BirdLife South Africa (BLSA) and the Endangered Wildlife Trust (EWT) have convened the Birds and Wind Energy Specialist Group (BAWESG), as well as the Birds and Wind Energy Forum (BAWEF) to assess policy, monitoring and research needs. Their most notable outputs have been Avian Wind Farm Sensitivity of South Africa (Retief et al. 2011) and the newly revised Birds and Wind Energy Best Practice Guidelines (Jenkins et al. 2015). The Environmental Impact Assessment (EIA) Guideline for Renewable Energy Projects, recently compiled by the Department of Environmental Affairs (DEA), has further reinforced mitigation measures (DEA 2015). Direct monitoring is a useful method of collecting data related to abundance and nesting sites (Jenkin et al. 2015). This technique is, however, extremely error-prone when assessing movements or density (Harmata et al. 1999; Cooper & Blaha 2002; Bigger et al. 2006). Visual observations are also restricted to good visibility.

Doty and Martin (2013) were the first to report avifaunal mortalities at a wind farm in South Africa. While monitoring efforts are ongoing at South Africa's operational wind farms, the relative young age of the local wind energy industry, has limited research output. A handful of wind farms (primarily on the West Coast) have integrated radar technology into their monitoring regimes (pers. comm.). As the wind energy industry is expanding and establishing in more provinces (DoE 2015), the range of affected bird species is also expanding, which demands different monitoring regimes. The Eastern Cape Province is amongst those that has an abundance of wind resources, which are already being exploited (DoE 2015). Eventually the overlap between wind farms and the range of more vulnerable species, like the Cape Vulture, will increase. Thus, the Cape Vulture was the subject of this study, and as one of the species' strongholds (Boshoff et al. 2009), the Eastern Cape Province served as an ideal location.

The aim of this study was to (1) define Cape Vulture tracks for automated target extraction from a radar database, (2) use that information to investigate Cape Vulture activity patterns, and (3) essentially assess the application of this methodology at proposed wind farms in South Africa.

3.2. Study Site

The site forms part of the proposed Umtathi Emonyeni WEF, about 30km west of Komga (-32.577°, 27.888°), in the Amathole District Municipality, Eastern Cape Province. Windlab Developments South Africa (Pty) Ltd (Windlab hereafter) have secured a total of 17 land parcels for this development.

All three radar placement sites (T1, T2 and T3) were located north of the R63 between Bisho (-32.849°, 27.438°) and Komga (-32.577°, 27.888°) [Figure 2.1]. Site selection was primarily driven by landscape features promoting the maximisation of the radar scan volume coverage. These features included topography and vegetation cover. Accessibility was also a major factor, and was responsible for the considerable overlap between the radar scan volumes of T1 and T2 (Figure 2.1).

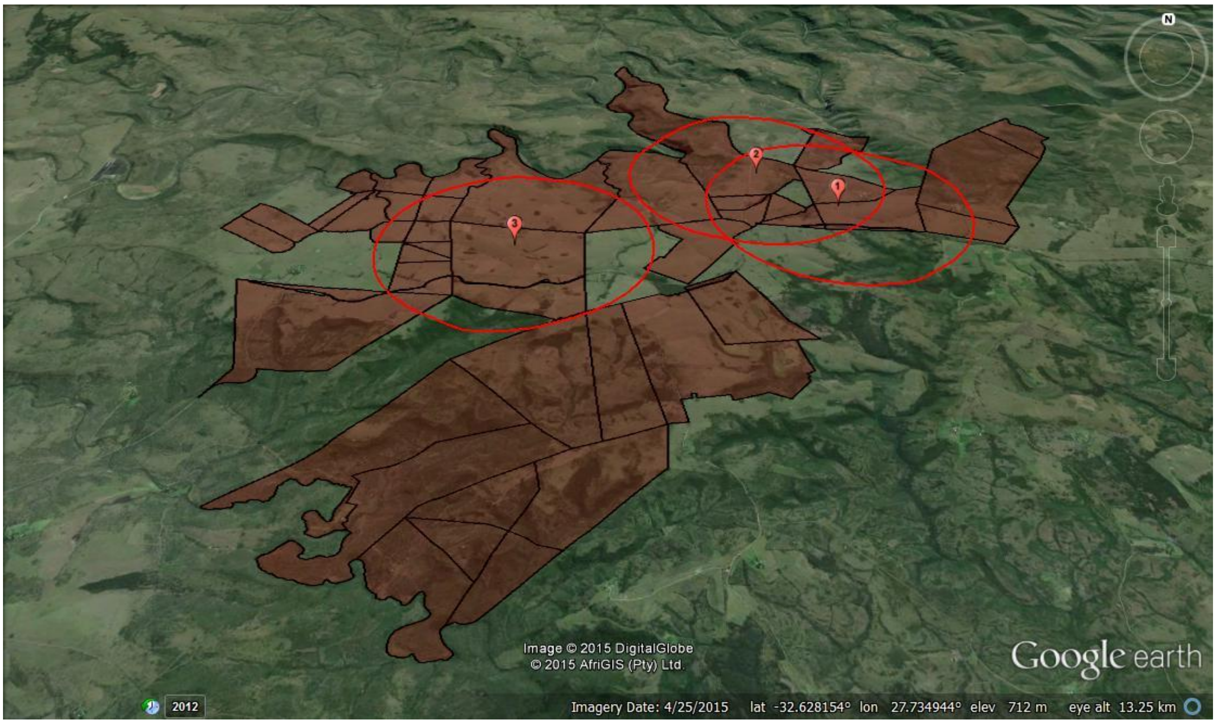

Figure 2.1: Land parcels secured for the proposed Umtathi Emonyeni WEF and the radar survey points (numbered accordingly), each surrounded by a 3km radar radius (red line).

Vegetation composition gradually transforms from *Acacia*-dominated Eastern Valley Bushveld and Bhisho Thornveld at T1 and T2, Amathole Montane Grassland speckled with *Eucalyptus* and *Acacia* forest patches at T3 (Mucina & Rutherford 2006). A mosaic of artificial water bodies covers the study area – an infrastructural adaptation to intensive livestock and crop agriculture. In the west, the Kubusi River, which is a tributary of the Great Kei River, north of the site. The flows of these perennial rivers have created steep gorges in the region's mountainous landscape. This has provided the cliff-nesting Cape Vulture with ample breeding sites, with the closest breeding colony (-32.380°, 27.880°) located about 20km north-east of the study site.

3.3. Study animal

Cape Vultures or Cape Griffons, as they are also known as, are endemic to the southern African subcontinent (Mundy et al. 1992). They are one of the largest raptors on the continent, with body lengths ranging from 100cm to 118cm, and wing spans reaching up to 2.3m (Sinclair et al. 2011). Adult birds are identified by their predominantly cream-coloured plumage, and dark tail and flight feathers. A bare grey-blue head and neck, yellow eyes, and black beak comprise the superior end of their bodies. The juveniles' slightly darker plumage, red neck and brownish eyes separate them from adult individuals. Audible vocalisations in Cape Vultures are limited to varying guttural noises, generally only observed at breeding colonies (Sinclair et al. 2011).

Late summer or early autumn generally mark the start of the Cape Vulture's breeding season, during which they lay a single egg (Boshoff & Currie 1981; Piper et al. 1981; Mundy 1982; Robertson 1986; Borello & Borello 2002). Having hatched approximately eight weeks later, the chicks spend more than four months as nestlings (Piper et al. 1981; Robertson 1986), before fledging in November/December, after which they usually leave the colony, before the next breeding season starts (Piper et al. 1981; Mundy 1982).

Like most vulture species, the Cape Vulture's diet consists primarily of ungulate carrion (Mundy 1982), the majority of which it now obtains from domestic livestock, due to extensive agricultural land uses (Robertson & Boshoff 1986; Komen & Brown 1993).

Their breeding population is mostly concentrated in the northern reaches of the former Transvaal province (Benson et al. 1990; Mundy et al. 1992; Whittington-Jones et al. 2011), and eastern South Africa, including the highlands of Lesotho (Brown & Piper 1988; Mundy et al. 1992; Boshoff et al. 2009), confining the majority of the global population to South Africa (Piper 1994, Botha et al. 2012). Zimbabwe, Botswana, and Namibia are, however, still home to some isolated Cape Vulture colonies (Borello & Borello 1987; Brown 1985; Borello & Borello 2002; Bamford et al. 2007; Botha et al. 2012).

Despite research and conservation efforts dating back to the 1950s (Paterson 1952; Jarvis et al. 1974; Mundy et al. 1980; O'Connor 1980; Mundy et al. 1992), the global Cape Vulture population is still declining (McKean & Botha 2007; Ogada et al. 2012; Ogada et al. 2015). Threats have included habitat loss (through changing land use practices and bush encroachment), collisions with anthropogenic structures, their use for traditional medicine and carrion poisoning amongst others (Boshoff & Anderson 2006). As of 2015, the conservation status of the Cape Vulture was classified as 'endangered', according to both the Red Data Book of Birds of South

Africa, Lesotho and Swaziland (Taylor et al. 2015), as well as the International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species (BirdLife International 2015). The species' decline has been dated back to the beginning of the 20th century (Ogada et al. 2012), and was already considered to be 'vulnerable and threatened' in the first edition of the South African Red Data Book for Birds (Siegfried et al. 1976). The global breeding population is now estimated to be less than 3000 pairs (Wolter et al. 2014).

3.4. Methods and Materials

3.4.1. Visual Monitoring

Visual monitoring was restricted to vantage point (VP) observations, with each VP located at least 100m from the respective radar placement site. A total of five replicates were completed from November 2014 to June 2015 – each one consisting of 12 days, with four days spent at each site. VP observations were conducted in two hour stints, amounting to 12 hours (06:00 – 18:00) per site.
The VPs were classified as VP1 (-32.57670°, 27.78832°; elevation: 664m), VP2 (-32.56123°, 27.76842°; elevation: 703m) and VP3 (-32.59330°, 27.71026°; elevation: 741m), and were selected based on field of view (FOV), accessibility and observable bodies of water (when available).
Visual targets were identified using 10×42mm binoculars (Bushnell) and Sinclair et al. (2011) as a reference guide. Movements of targets were plotted using a cross-platform desktop geographic information system (GIS) [QGIS 2.6 Brighton]. Both radar placement sites and VPs were used as reference points on each site map, along with Google Earth™ imagery. Variables recorded during visual observations were species, time, flight direction, flight behaviour, flight height, visibility and precipitation. The path of the flight was plotted either as a multi-jointed line or polygon, depending on the species' flight behaviour – i.e. polygons represented the general area in which the target moved. Flight behaviours included direct commuting (gliding or flapping), thermal soaring (or cliff soaring), perching or actively hunting. Flight height estimation was divided into three categories: <30m, 30m – 150m, and >150m. These parameters are based on the maximum extent of the rotor-swept area

(RSA). Visibility was recorded as a distance (in km), referring to the depth of the FOV. Recorded datasets were transcribed to a Microsoft Office Excel spreadsheet. Latitudinal and longitudinal coordinates were extracted for each track 'joint'. Moreover, Windlab provided meteorological data (wind speed, wind direction, atmospheric pressure and ambient temperature) for each replicate, with readings made in 10 minute intervals. These data were then matched with the corresponding visual observation. Apart from Cape Vultures, a list of priority species was compiled, whose movements were also recorded (Appendix). The selection of these species was based on their assignment of a Species Priority Score or susceptibility to wind energy developments (Retief et al. 2011), as well as their local occurrence (Southern African Bird Atlas Project). Factors taken into consideration for such a score are the species' conservation status, structural factors and behavioural factors (Retief et al. 2011).

3.4.2. Radar Monitoring

The radar unit used in this study was the EchoTrack™ Omni-directional Radar-Acoustic sampling system, which consists of a 25kW, 3cm wavelength surveillance Raccal Decca BridgeMaster E, and a 1.8m X-band antenna. The system is mounted on a customised Venter© Kiosk Trailer (overall height: 2585mm, overall length: 3205mm, overall width: 2000mm). In order to enhance coverage of target height, azimuth and range, the antenna was modified with a 26° tilt (Millikin & Buckley 2001). Captured data are digitised via a Sigma Engineering RSi 3000 radar digitising and recording system (Millikin 2001). Its range and angle resolution is 7.5m and 0.5°, respectively, with a height accuracy of 15m. A total scan volume of 31.62km^3 was generated at each placement site, comprising of a 2–3km radius and a maximum height of 1950m. The required power was provided by a Honda® EU30is inverter generator.

Coordinates for each placement site were fixed at the tip of the trailer, while any offset was minimised by setting up the unit to face true north. Sampling replicates consisted of three and a half days of diurnal monitoring (sunrise to sunset), and one overnight sampling period. The overnight sampling was generally completed on the first day, if weather conditions permitted. Half a day was always required to move and set up the unit. Sampling was discontinued for refuelling of the generator or if unfavourable weather conditions (i.e. electrical storms) threatened to compromise the safety of the unit and the observer. To allow the radar to run throughout the night, the recording and scheduling software was designed to measure days from 12:00, instead of midnight.

3.4.3. Target Extraction

EchoTrack software defined each airborne target's flight path as a sequence of track points, with each point expressed as coordinates and height above ground (every 1 – 3s). Aggregations of birds were separated into individual tracks by the radar.

All radar tracks were pooled into a collective database where they were assigned to corresponding visual observations. These matches were based on congruent times, locations and flight directions, and ultimately aided in the confident identification of species. Any unmatched visual observations were subject to review and those with only one possible corresponding radar track were assigned the species identification, with the assumption that delays in time or distance were attributable to observer-related judgement. Any remaining unassigned visual observations were left unmatched.

Information from this matching was used to develop the algorithm to identify Cape Vultures from radar flight paths without a corresponding visual observation. Radar-determined flights were first separated into birds (not manmade objects, bats or insects) by size and speed, and then further identified as Cape Vultures from other birds by size and speed.

Sections of the recordings that corresponded to visual observations of Cape Vultures were replayed to isolate the tracks and determine the characteristic track parameters and how those differed from other species identified at the same time.

3.4.4. Cape Vulture Activity

Once all Cape Vulture tracks were extracted from the radar dataset, the time of the observation, as well the corresponding sunrise and sunset times for that day, were converted into seconds. These values were then used to determine the temporal difference between each observation, and sunrise and sunset. As soon as this difference was obtained, it was further converted into hours. The range (minimum and maximum) of these differences was divided into hourly intervals, to which each observation was then allocated. The same procedure was applied to visual observations.

Mean climbing rates were obtained by, firstly, isolating all ascending Cape Vulture flight tracks. Thereafter, the difference in height (in metres) between the start- and end-point of each track was divided by its duration (in seconds), producing a climbing rate for each track. Climbing rates were then sorted according to time of recording, and a mean climbing rate for every hour of the day was generated.

Due to the fact that each track consisted of a sequence of points, median heights of all Cape Vulture tracks were attained, before they were also divided into hour-long periods, relative to sunrise and sunset times. The mean flight height for each hour was finally calculated.

3.5. Results

Cape Vultures had a higher reflectance (size) than other species, except for the Secretarybird (*Sagittarius serpentarius*) [size 300-10000 pixels] which also exhibited airspeeds higher than 10m/s, but at sizes greater than 2000 pixels. Airspeeds for Cape Vultures were slower (< 30m/s) than those for Secretarybird tracks (> 30m/s). The algorithm that defined the separation between Cape Vulture and the species most likely to be confused with it in the data, was: *(400 × average track airspeed) - reflectance - 10000*. This calculation for a Cape Vulture was consistently ≤ 0, where this calculation for a Secretary bird was ≥ 0.

This algorithm (EchoTrack Inc.) was applied to all radar data to provide identification of Cape Vultures during the radar processing, such that output text files had 'Cape Vulture' under species identification. Only the matched tracks for Cape Vulture (n = 42) and Secretarybird (n = 2) were characterized further for threshold values of flight characteristics (size, speed, etc.), which allowed further assignment of tracks based on radar characteristics alone (i.e. beyond periods with visual observations).

Cape Vulture activity was at its highest between seven and eight hours (355 observations/hour) after sunrise, according to the radar observations (Figure 2.2).

Figure 2.2 depicts an activity peak between five and six hours (12 observations/hour) after sunrise, based on visual observations. Within the hour after sunrise, the radar data revealed a considerable increase in Cape Vulture activity (198 observations/hour) [Figure 2.2]. Cape Vulture radar tracks (n = 2159) were recorded up to six hours before and about ten hours after sunrise (Figure 2.2). No visual observations were made until two hours after sunrise, while the Cape Vultures were visually observed ten hours after sunrise (Figure 2.2). All visual observations (n = 37) were noted during the course of eight hours, within which 74.5% of the radar observations were recorded.

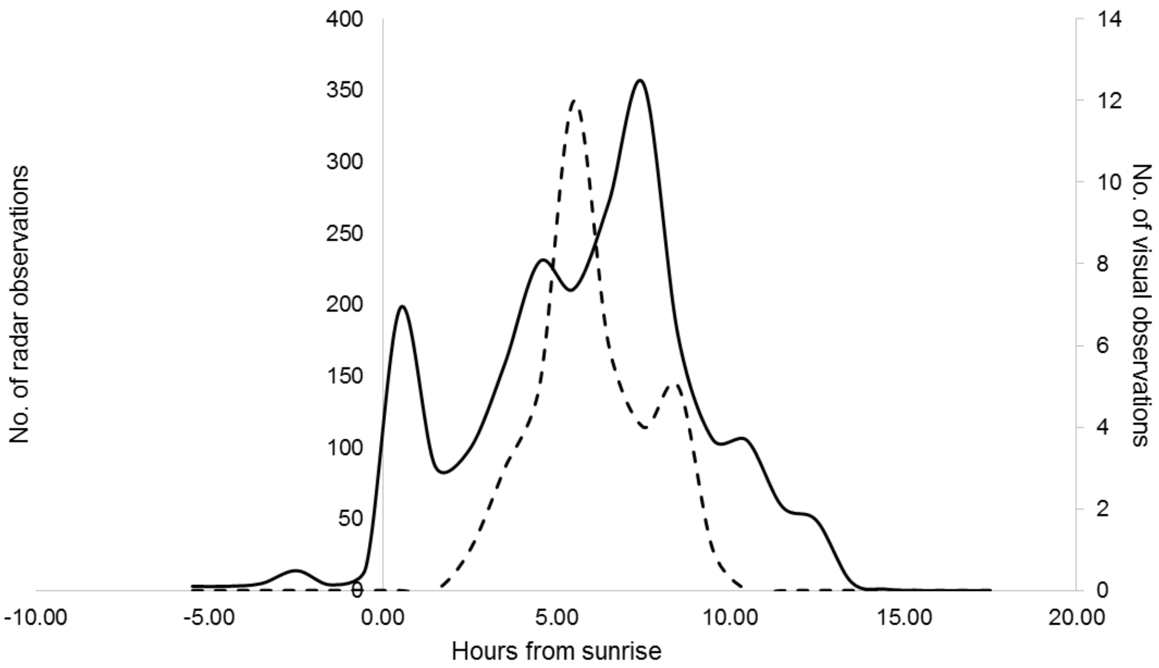

Figure 2.2: Cape Vulture movement frequency expressed as number of observations per hour from sunrise (primary vertical axis). Visual observations (dashed line) are scaled on the secondary vertical axis, whereas radar observations (solid line) are scaled on the primary vertical axis.

Most radar-observed Cape Vultures (275 observations/hour) were active between five and six hours before sunset (Figure 2.3). Analyses of visual observations yielded two conspicuous activity peaks – these occurring between four and six hours before sunset, and the other between seven and eight hours before sunset (Figure 2.3). Both visual and radar observations exhibited a dip in activity rate between peak hours of the day (Figure 2.3). Visually monitored activity rates fell between six and seven hours (4 observations/hour) before sunset, while radar monitored rates experienced a sudden decline, seven to eight hours before sunset (Figure 2.3). Visual observation extended across a period of seven hours, which started approximately nine hours before sunset and ended three hours before sunset (Figure 2.3). Almost 70% of pre-sunset radar observations were restricted to those hours, with the first observations made 18 hours before sunset, and the last, about two hours after sunset (Figure 2.3).

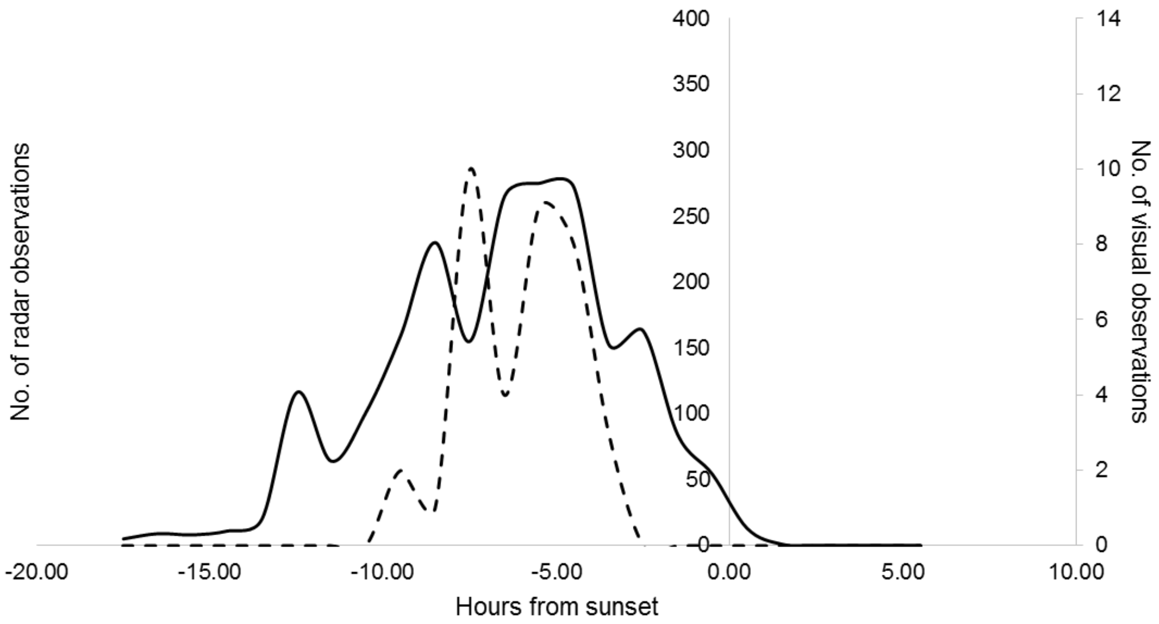

Figure 2.3: Cape Vulture movement frequency expressed as number of observations per hour from sunset (primary vertical axis intersect). Visual observations (dashed line) are scaled on the secondary vertical axis, whereas radar observations (solid line) are scaled on the primary vertical axis.

Out of all 2159 Cape Vulture radar tracks, 671 (31%) were found to be gaining altitude and were hence assigned a climbing rate. Within the last hour before sunrise, the mean climbing rate (3.91m/s; SE 2.76m/s; n = 2) increased substantially (Figure 2.4). The highest mean climbing rate (5.01m/s; SE 0.66m/s) was recorded between three and four hours after sunrise (n = 59) [Figure 2.4]. At the peak of Cape Vulture activity, the mean rate was 4.56m/s (SE 0.42m/s; n = 119), after which it steadily declined (Figure 2.4).

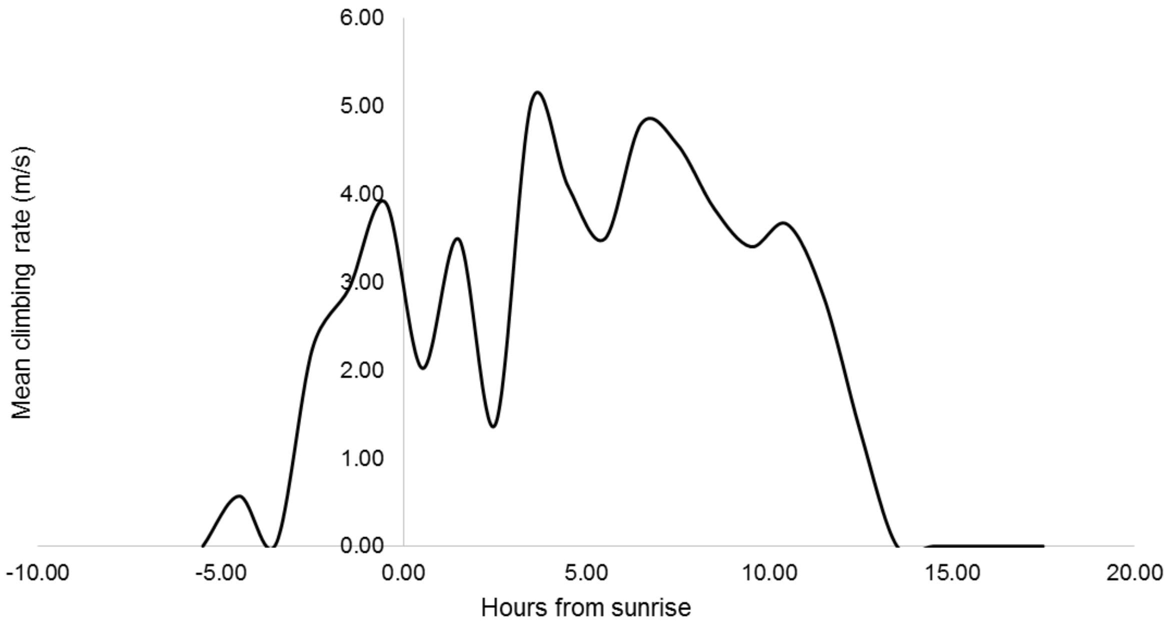

Figure 2.4: Mean climbing rate of Cape Vulture radar tracks per hour, with reference to the time of sunrise (primary vertical axis intersect).

Between 13 and 14 hours before sunset the mean climbing rate peaked at 8.35m/s (SE 4.97m/s; n = 3) [Figure 2.5]. Generally though, the mean climbing rate coincides with the frequency of Cape Vulture observations. During the most active period of the day (between five and six hours before sunset), a mean climbing rate of 4.72m/s (SE 0.59m/s; n = 94) was documented.

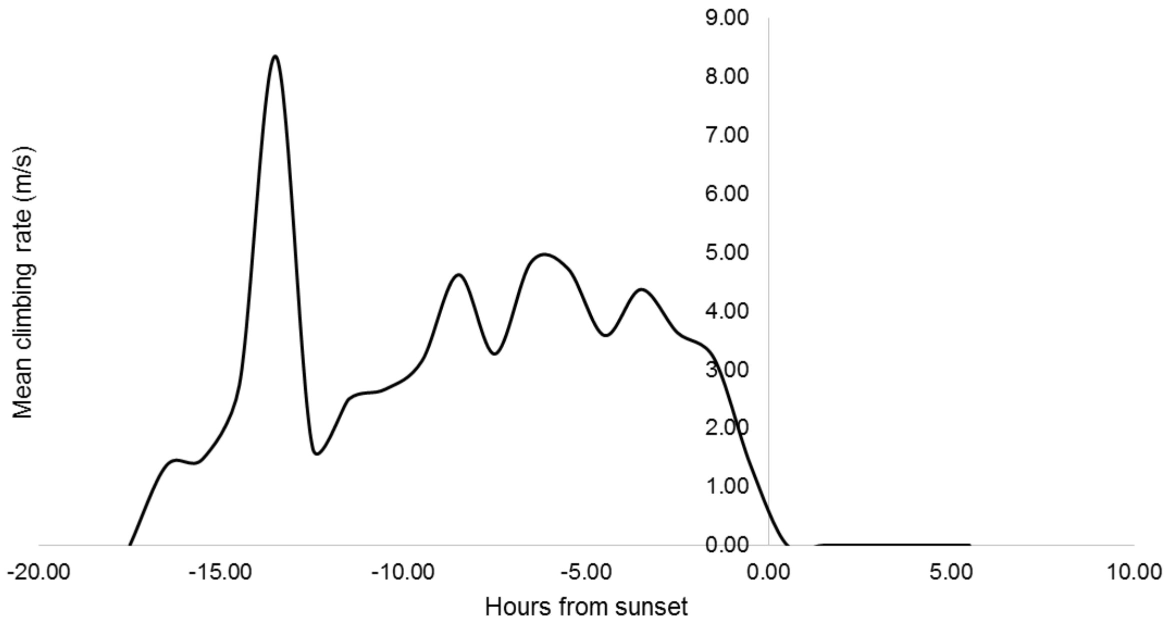

Figure 2.5: Mean climbing rate of Cape Vulture radar tracks per hour, with reference to the time of sunset (primary vertical axis intersect).

The three Cape Vulture flights recorded between four and five hours before sunrise yielded the highest mean (345.1m; SE 45.6m), after which the mean flight height declines again steeply, before steadily rising again after sunrise (Figure 2.6). During the hours after sunrise, the highest mean flights were observed between four and five hours (194.5m; SE 10.2m; n = 230), and five and six hours (204.1m; SE 11.7m; n = 211) [Figure 2.6]. Between three and four hours before sunrise mean flight heights (n = 5) were at their lowest (8.2m; SE 3.0m). For 10 of the 21 hours (47.6%) that yielded observations, the mean height of targets fell within the RSA (30m – 150m). This, however, only comprised 23.7% (n = 502) of all observations.

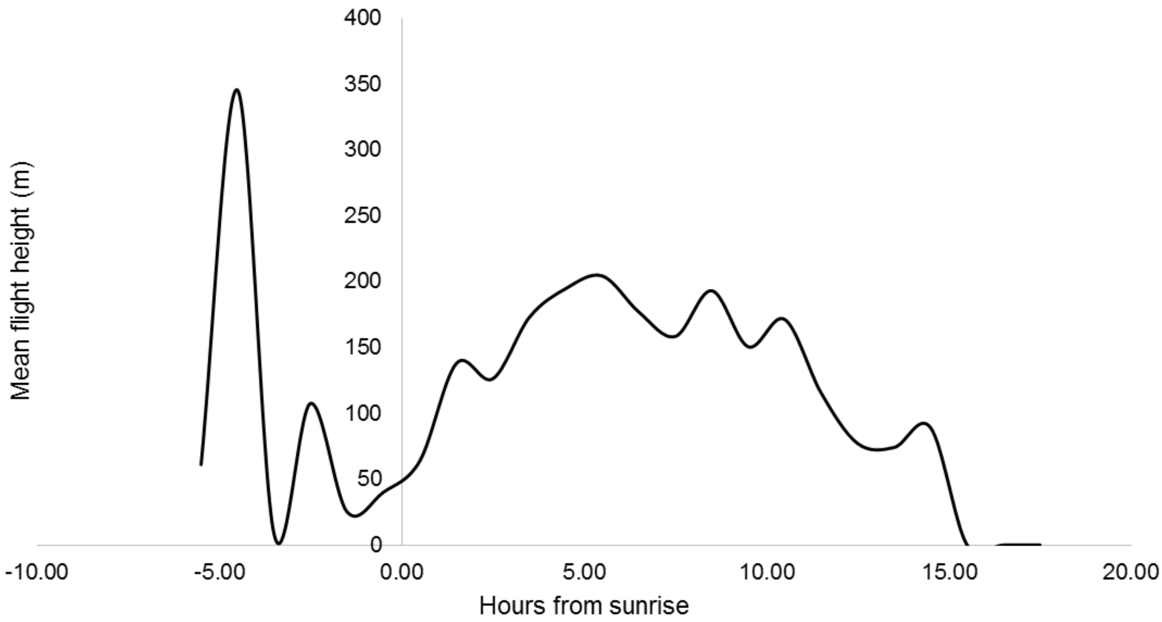

Figure 4.6: Mean height of Cape Vulture radar tracks per hour, with reference to the time sunrise (vertical axis intersect).

In the hours before sunset, mean flight heights picked up throughout the day, until reaching a diurnal peak height (191.8m; SE 14.5m; n = 153) between three and four hours before sunset (Figure 2.7). One flight was recorded between one and two hours after sunset, which yielded the highest mean height (312m) [Figure 2.7]. The lowest mean flight height (8.8m; SE 3.3m; n = 5) was documented between 17 and 18 hours before sunset. More than 50% of mean target flight heights were located within the RSA (30m – 150m), which equated to 608 observations out of 2123 (28.7%). A total of 681 tracks (32.1%) expressed median height values within the RSA.

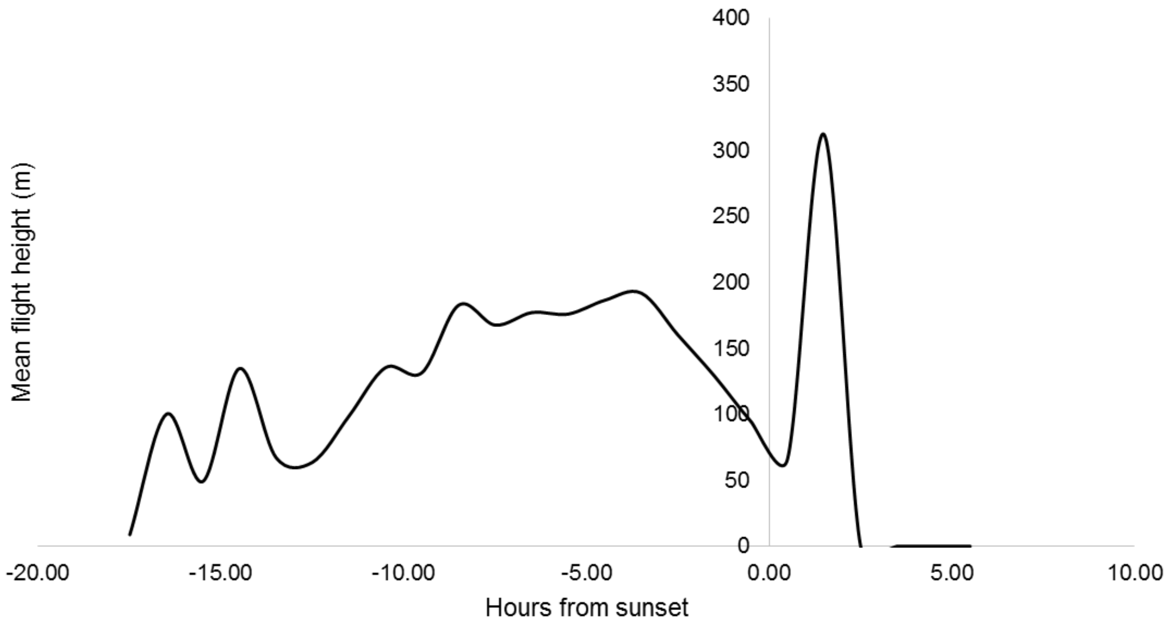

Figure 2.7: Mean height of Cape Vulture radar tracks per hour, with reference to the time sunrise (vertical axis intersect).

3.6. Discussion

Although, the process of separating Cape Vulture tracks from those of other birds provided very little to no overlap, a notable gap in sample sizes has to be considered. The number of Cape Vulture observations were far superior to those of other species. More recordings of other species could have potentially produced different results. Nevertheless, these results demonstrate radar's capacity to identify Cape Vultures, with visual supplementation. In terms of body mass, the Cape Vulture was the largest raptor in the area, weighing up to 11kg (Sinclair et al. 2011). A Secretarybird, on the other hand, weighs less than half of that (Sinclair et al. 2011), and is very similar in morphology and flight behaviour to the Blue Crane (*Anthropoides paradiseus*) or Grey Crowned Crane (*Balearica regulorum*), which were also observed at the site. Collectively, observations for both crane species were twice as many as for Secretarybirds. Hence, the reliability of the small sample size may have to be called into question, because the distance from the radar, as well as the aspect of the target also influence the reflectance strength. The sample size of the Cape Vulture observations, however, was large enough to draw relatively reliable conclusions from it.

Much like other vulture species, the Cape Vulture relies heavily on ascending thermal or orographic air currents (Bohrer et al. 2012; Duriez et al. 2014). By doing so, they minimise energy expenditure, which, considering their size and foraging ranges is essential. Data obtained from five satellite-tracked Cape Vulture adults, produced a mean range of 38 327km^2, while two juveniles covered an average area of 482 276 km^2, over a period of six months (Bamford et al. 2007). A recent study on Eurasian (*Gyps fulvus*) and Himalayan Griffon Vultures (*Gyps himalayensis*) provided evidence of the energy efficiency of soaring flight, with the study subjects exhibiting almost baseline heart rates while soaring (Duriez et al. 2014).

Given that Cape Vulture observations were most abundant during the middle of the day, it may be safe to assume that this is related to increased thermal convection. This is supported by the closely coinciding mean climbing rates, as well as mean flight heights during those periods. Spaar and Bruderer (1999) recorded similar climbing rate trends amongst Steppe Eagles (*Aquila nipalensis*) with peak values reached at noon. The high mean flights recorded shortly before sunrise and after sunset can be deemed as outliers, given their extremely small sample size (Figure 2.6; 2.7). Updrafts are, however, hard to predict because they are driven by a combination of topography, climate and weather (Hoover & Morrison 2005).

The fact that the average target occupied the airspace above the RSA during peak activity hours, also adds another perspective for mitigation decision-making – the implication being that high activity rates do not necessarily translate to high-risk flight behaviour. Considering the findings in Chapter 2, the target placement inaccuracy of visual observations could result in skewed assessments, which could have undesired repercussions for bird populations. Moreover, high activity rates do not refer to abundance but observation frequency, which is one of the integral variables to consider when conducting a risk assessment.

While all visual observations fell within a seven or eight hour time frame, the first Cape Vulture observations were only made at least two hours after sunrise and the last about three hours before sunset. Radar observations, however, suggest that some (albeit very little) Cape Vulture activity was recorded before sunrise and after sunset. Based on personal observations at the Vumenjani Colony and a nearby roosting site, most birds generally returned well before sunset, while their departure from the colony was never observed. Records of Cape Vultures flying at night are not available in the literature. While a lack of thermals and the relative unreliability of unverified radar tracks during those hours of the day, may suggest that these recordings are misleading, it may provide more insight into Cape Vulture activity. The Best Practice Guidelines drawn up by Jenkins et al. (2015), do recommend that VP observations commence before sunrise and end after sunset. This still poses a visibility issue for the observer.

Ranging behaviour is a vital determinant of site-specific activity patterns, as Cape Vultures have been found to forage across vast distances (Roberston & Boshoff 1986; Brown & Piper 1988; Bamford et al. 2007). This study site's relatively close proximity to a breeding colony must also be considered as a contributing factor to the results obtained. Due to time constraints, the duration of this study did not include all four seasons (or 12 months). Robertson & Boshoff (1986), however, noted very little seasonal variation in foraging patterns amongst Cape Vultures at the Potberg Colony in the Western Cape Province. They also suggested that individuals from that particular colony spent up to seven hours foraging per day, and almost four hours on average.

Although direct or visual observations have provided a relatively accurate representation of Cape Vulture activity patterns, based on the radar data, their limitations are apparent. Visual verification is, however, essential for the effectiveness of radar. While this study's focus was restricted to one site and one species, it has given a valuable indication of how radar could be implemented, not only in collision risk assessments, but also in the study of bird activity and movement. Subsequently, this study should be augmented by further research across more geographically heterogeneous landscapes. Referring to Cape Vultures in particular, this would vastly improve extant knowledge on their activity and flight behaviour. Given the current plight of South Africa's vultures (BirdLife International 2015; Ogada et al. 2015; Taylor et al. 2015), a technology-based mitigation strategy for emerging threats such as wind turbines, could greatly accelerate and optimise conservation efforts.

Data collected in this study are a valuable asset for mitigation measures such as the temporarily shutting down of turbines. This particular strategy has been one of the most effective approaches in minimising collision-related bird fatalities (Marquez et al. 2014). Temporary shutdowns were successfully implemented at wind farms within the Cadiz region in southern Spain (de Lucas et al. 2012). The combined 296 turbines have been responsible for one of the highest raptor mortality rates ever recorded (de Lucas et al. 2008; Ferrer et al. 2011). Ceasing operation of particularly hazardous turbines for short periods of the day decreased Eurasian Griffon Vulture mortalities by 50%, while only lowering energy production by 0.07% (de Lucas et al. 2012). De Lucas et al. (2012) also reported that most collisions occurred between two hours after sunrise and two hours before sunset. This means that the turbines can be allowed to operate uninterrupted during the night, with only occasional shutdowns during diurnal hours. Actively monitoring vultures at a WEF is a costly and laborious exercise. Thus, collecting accurate and sufficient pre-construction data on priority species at a given site could afford developers the opportunity to draw up an effective mitigation strategy that requires fewer resources. Ensuring that the visual observation sample size is large enough to confidently develop a radar algorithm for a species or group of similar species is vital. Jenkins et al. (2015) recommend that VP observations should be conducted for at least 12 hours per season per VP. Even though this study was not seasonally orientated and only utilised three VPs, the time spent at each VP was between 50 and 60 hours (considering unforeseen interruptions etc.). Given the amount of time spent monitoring, the number of visually verified radar tracks (42) is relatively small. The trends recorded by both radar and observer are generally similar, but in order to confidently execute a mitigation strategy, a larger sample size may have to be gathered. This is especially true for sites frequented by highly vulnerable species, such as the Cape Vulture.

3.7. Conclusion

Using radar as a tool to monitor the activity of priority bird species during the baseline monitoring or pre-construction phase of a WEF, provides a good foundation for reliable approval or mitigation management decisions. Supplementing radar monitoring with direct or visual observation has the capacity to define certain parameters for a single or a group of morphologically and behaviourally similar species, in order to automatically extract the desired radar tracks. Adopting this approach for sensitive sites, could greatly reduce any potential long-term collision risks.

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4. Management Recommendations

Confronted by a host anthropogenic threats (Boshoff & Anderson 2006), the plight of the Cape Vulture looks critical, which local and international conservation bodies have recognised (BirdLife International 2015; Taylor et al. 2015). While more pressure is unwelcome, the emerging threat created by wind turbines presents a somewhat unique management opportunity. Being a regulated developing industry, whose induced environmental damages are purely 'collateral', calculated measures can be taken to minimise these damages. However, such measures need to be implemented at the initial phases of development. With wind energy related impacts on birds reported at wind energy facilities (WEF) across the globe (Barrios & Rodríguez 2004; de Lucas et al. 2008; Nygård et al. 2010; Dahl et al. 2012; de Lucas et al. 2012; Bellebaum et al. 2013; Loss et al. 2013; Pagel et al. 2013; Hernández-Pliego et al. 2015), South Africa has been afforded the opportunity to draw lessons from others' mismanagement, and apply it in a local context. Hence, this study was aimed at providing recommendations for an improved pre-construction monitoring protocol of bird movements.

These recommendations strongly endorse the use of radar, and while some bird surveys are beyond technology's capacity (i.e. abundance, breeding and species richness surveys), radar systems probably offer the most accurate assessment of bird movements, through and around a site. Radar's limitations are not only technical (Eastwood 1976), but also economic. Financial implications often restrict the employment of radar technology during avian assessments – a concern acknowledged by several authors of monitoring guidance documents (SNH 2009; Jenkins et al. 2015). Others have, however, highlighted the need to augment monitoring efforts with technological aids (CDC/CDFG 2007; NYSDEC 2009). These augmentations are of particular value to the monitoring of large-scale bird migrations, nocturnal bird movements, and the movements of priority species. All impacts associated with wind farms are specific to the location of the development, where species assemblages, topography, weather patterns, turbine designs and turbine configuration may vary (Marquez et al. 2014). It is therefore essential that the monitoring regime for each site is also adapted accordingly. South Africa's most recent set of monitoring guidelines recognise the value of the quality of radar surveys: "…use of a radar system is likely to add significant value to any monitoring project, and may be essential at certain sites where it is critical to obtain accurate data on large-scale movements of birds, or movements of significant numbers of highly threatened species, that are thought (or known) to take place at night or in conditions of poor visibility" (Jenkins et al. 2015)

While these are reasonable recommendations, it may be advisable to use radar systems for monitoring "movements of significant numbers of highly threatened species" (Jenkins et al. 2015), regardless of the timing of these movements or the conditions of visibility. The findings from Chapter 2 strongly support this suggestion. Although the observer's relative lack of experience may somewhat compromise the credibility of these findings, the human eye remains an unreliable estimation tool for distance and height. Moreover, the preceding Best Practice Guidelines (Jenkins et al. 2012) mentioned the use of radar being "non-negotiable at certain sites" – something that should have been included by Jenkins et al. (2015).

Issues, such as the radars' mobility, and capacity to discriminate species and individual birds are often brought into question (SNH 2009). Radar technology has, however, become incredibly versatile and adaptable. Mobile units fitted with X- or S-band radar systems (such as the one used in this study) often allow for the monitoring of birds at sites that might have limited accessibility. Their mobility also compensates for their comparatively short range (Millikin 2005; Nohara et al. 2007). What these marine surveillance radars lack in range, they also make up for in accuracy, with much higher range and angle resolutions, as well as greater height accuracy (Harmata et al. 1999; Millikin 2005). Accessibility was a minor obstacle at our study site, which resulted in a considerable overlap between two radar scan volumes, and a minimal gap between two others. Inaccessibility was largely restricted to the design of the trailer, as well as to the sensitivity of the equipment. Mounting the radar system on a smaller, lighter and higher set trailer would vastly improve its manoeuvrability. Also, ensuring that particularly sensitive hardware is secured appropriately, would also allow for transport on poorer roads. These are all technical issues that can be solved with relative ease. Accessibility is, however, not just constrained by the design of the unit, but also by habitats. Dense and tall vegetation structures do obstruct the reflectivity of radar targets.

While the costs associated with radar monitoring are often a deterrent for developers, it would be worthwhile to conduct a cost-benefit analysis of the long-term financial implications of investing in a high-grade pre-construction monitoring regime. It could be hypothesised that the costs of compensating for exceptionally high mortality rates at a WEF would clearly outweigh any expenditure for comprehensive monitoring programmes. Such a compensation could come in the form of decommissioning particularly hazardous turbines.

A recently completed dissertation by McCarthy (2015) estimated the costs associated with decommissioning wind turbines in Sweden. The highest estimate amounted to just less than ZAR 790 000 per turbine, which included civil, electrical and turbine costs. These costs applied only to the decommissioning of entire wind farms at the end of their life-span, which means that expenses were slightly alleviated by the residual value of the turbines (i.e. scrap metal) [McCarthy 2015]. In the event of individual turbines being decommissioned prematurely, substantially more costs would be incurred. This all has to be applied to a local context, of course.

In order for such a scenario to play out, an appropriate legislative framework has to exist. While the possibility of prosecution would be incentive enough to urge prospective developers to optimise mitigation measures, South Africa's legislation offers limited incentive. The Environmental Impact Assessment (EIA) Guideline for Renewable Energy Projects (DEA 2015) refers to the National Environmental Management: Biodiversity Act (Act 10 of 2004): "The Act identifies restricted activities involving listed threatened, protected or alien species. These activities include picking parts of, or cutting, chopping off, uprooting, damaging or destroying, any specimen of a listed threatened or protected species."

According to the recently drafted EIA Regulations (Environmental Management Act, Act 107 of 1998), activities such as the development of wind energy can be directed to cease, should there be evidence that environmental authorisation for said activity "…was obtained through fraud, non-disclosure of material information or misrepresentation of a material fact …".

These regulations do not, however, signify the intent and urgency that is required to ensure the preservation of some of South Africa's priority bird species – especially its vulture species. Enforcement of environmental law in the United States has recently seen PacifiCorp Energy sentenced to USD 2.5 million in fines, compensation and community service, after pleading guilty to constructing two WEFs in Wyoming, despite the knowledge of high collision risks amongst Golden Eagles (*Aquila chrysaetos*) and other protected bird species at the sites (DOJ 2014).

While the United States' legal system can hardly be compared to that of South Africa, it provides a valuable blueprint. Research, in turn, provides us with a vehicle to drive legislation and policy adaptation. To inspire such adaptations, certain research priorities need to be identified. Wang et al. (2015) have proposed that in order to further our understanding of the variables driving WEF related impacts on birds, the quality of monitoring data, as well as industry cooperation and support need to improve. The outcomes of Chapter 2 and 3 underline those needs. Close cooperation between researchers and developers has the potential to be mutually beneficial (Wang et al 2015). Similar to this study's facilitation, developers can provide researchers with funding and access to WEFs, while the research output can be used to make recommendations for the layout of the wind farm or the operations schedule. Since, high-quality research is both resource and time consuming, South Africa's environmental sector cannot afford to be wasteful with either.

Vulture populations are particularly vulnerable to any newly introduced threats (Boshoff & Anderson 2006). Ogada et al. (2015) have described the current vulture population declines in Africa as a 'crisis'. A similar vulture crisis was experienced on the Indian subcontinent recently (Prakash et al. 2003; Baral et al. 2004; Gilbert et al. 2004; Watson et al. 2004; Cuthbert et al. 2006). Devastating declines in numbers of three carrion-feeding species was primarily related to the ingestion of a non-steroidal anti-inflammatory drug known as Diclofenac, which ultimately caused renal failure (Green et al. 2004; Shultz et al. 2004; Swan et al. 2006). Following the devastating impacts on south Asia's vulture populations, the drug was banned in Pakistan, Nepal and India in 2006 (Pain et al. 2008), and since then population increases have been observed (Chaudhry et al. 2012).

While equally alarming, African vultures are experiencing a more protracted crisis than their Asian counterparts (Ogada et al. 2015). Managing an exceptionally wide range of threats presents conservationists with an overwhelming task. Mitigating each threat as efficiently as possible, therefore, becomes even more important. This study has not only demonstrated how technology can be applied to monitor endangered species, like the Cape Vulture, but also how its practical application has the potential to contribute to ensuring their survival.

4.1. References

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APPENDIX

List of priority bird species on site, based on their occurrence according to the Southern African Bird Atlas Project (SABAP), and priority scores assigned to them by Retief et al. (2011).

Species Priority Score	Scientific Name	Common Name	Min-Max Body Length (cm)	Min-Max Body Mass (g)
385	*Gyps corprotheres*	Vulture, Cape	100-118	7400-10800
330	*Polemaetus bellicosus*	Eagle, Martial	78-86	2400-5200
325	*Circus maurus*	Harrier, Black	42-50	350-600
320	*Anthropoides paradiseus*	Crane, Blue	100-120	4000-5500
320	*Sagittarius serpentarius*	Secretarybird	125-150	2800-5000
310	*Ciconia nigra*	Stork, Black	95-110	2500-3200
300	*Neotis denhami*	Bustard, Denham's	90-120	4000-14000
300	*Circus ranivorus*	Marsh-Harrier, African	44-50	360-680
294	*Balearica regulorum*	Crane, Grey Crowned	100-110	3000-4000
290	*Aquila verreauxii*	Eagle, Verreaux's	80-96	3000-5600
290	*Haliaeetus vocifer*	Fish-Eagle, African	63-73	2000-3800
290	*Bucorvus leadbeateri*	Ground-Hornbill Southern	90-130	2500-6000
284	*Falco naumanni*	Kestrel, Lesser	26-32	110-180
280	*Ardeotis kori*	Bustard, Kori	110-140	4500-18000
280	*Falco biarmicus*	Falcon, Lanner	36-48	420-800
270	*Stephanoaetus coronatus*	Eagle, African Crowned	80-98	2600-4200
270	*Eupodotis senegalensis*	Korhaan, White-bellied	52-60	1200-1600
250	*Buteo rufofuscus*	Buzzard, Jackal	55-62	900-1700
220	*Ciconia ciconia*	Stork, White	100-120	2400-4000
210	*Buteo vulpinus*	Buzzard, Steppe	46-52	540-920
209	*Poicephalus robustus*	Parrot, Cape	30-35	270-320
190	*Lophaetus occipitalis*	Eagle, Long-crested	52-58	810-1300
190	*Polyboroides typus*	Harrier-Hawk, African	60-66	620-950
190	*Pandion haliaetus*	Osprey	52-68	1250-1850
190	*Asio capensis*	Owl, Marsh	35-38	230-370
185	*Oenanthe bifasciata*	Chat, Buff-streaked	16-17	31-38
184	*Vanellus melanopterus*	Lapwing, Black-winged	26-28	150-200
174	*Elanus caeruleus*	Kite, Black-shouldered	30-33	210-290
170	*Bubo africanus*	Eagle-Owl, Spotted	43-50	500-1100
170	*Accipiter rufiventris*	Sparrowhawk, Rufous-chested	30-38	105-210